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Effects of Anxiety and Exercise-induced Fatigue on Operational Performance

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Effects of Anxiety and Exercise-induced Fatigue on Operational Performance

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad Doctor aan
de Vrije Universiteit Amsterdam,
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in het openbaar te verdedigen
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van de Faculteit der Bewegingswetenschappen
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door
Nicky Nibbeling
geboren te Maastricht

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copromotor:	dr. R.R.D. Oudejans

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General introduction

Introduction

Anxiety and exercise-induced fatigue are inherent to operational performance. Infantry soldiers, for instance, have to deal with exercise-induced fatigue as they march over heavy terrain, lift equipment, and carry backpacks. At the same time, they are under the constant threat of an upcoming hostile attack leading to high levels of anxiety. Still, in the midst of a battle while fatigued and anxious, soldiers have to be able to distinguish between friendlies and enemies while remaining tactically focused and while maintaining their perceptual-motor skills, such as shooting their firearms (e.g., Ward, Farrow, Harris, Williams, Eccles, & Ericsson, 2008; Wilson, Salas, Priest, & Andrews, 2007).

The current thesis focuses on operational behavior under elevated levels of anxiety and exercise-induced fatigue. However, operational behavior is far too complex to capture in one experiment. First, at least three different types of tasks can be distinguished in the operational domain that are worth examining; aerobic tasks (e.g., walking, running), perceptual-motor tasks (shooting), and cognitive tasks (e.g., decision making & vigilance). Second, soldiers' success on the battlefield will (among other things) depend on how well they can perform several tasks concurrently. They have to communicate coordinates while walking and be vigilant to their environment even when they are shooting. Third, soldiers often have to deal with multiple stressors that occur simultaneously. Although the separate effects of anxiety and exercise-induced fatigue on some of these tasks have been examined in detail, others have been left unattended. Especially, there is still little research on effects of anxiety and exercise-induced fatigue on combinations of tasks and on the combined effects of anxiety and exercise-induced fatigue on task performance.

Therefore, the first aim of the current thesis was to further our understanding of the separate and combined effects of anxiety and exercise-induced fatigue on tasks, and combinations of tasks, that are essential to operational performance. To that aim, first, three laboratory-based studies were designed to test some basic constructs regarding effects of anxiety and exercise-induced fatigue, before proceeding to testing real infantry soldiers in a field setting.

Moreover, experiments are rarely conducted in the soldier's working environment because of the risk of getting injured or killed. Computer simulations might provide a possible solution to the examination of soldier performance while avoiding the risk of getting injured. If we would be able to successfully model the effects of for example anxiety on soldier performance, then computer models might be able to predict the effects on performance in real life-threatening situations. This knowledge might help the development of a better preparation for these kinds of situations. An architecture that allows for the implementation of simulation models for operational performance is the CHAOS *(*Capability based Human performance Architecture for Operational Situations) architecture (Ubink, Aldershoff, Lotens, & Woering, 2008; Ubink, Lotens, & Woering, 2010). CHAOS incorporates a variety of human subsystems (i.e., cognition, information processing, motor skills) that interact with each other in order to simulate performance of the soldier or the rapid responder. The second aim of this thesis was to implement part of our experimental data in the CHAOS architecture and investigate the validation of the model using the other half of the empirical data.

Effects of anxiety on performance

Anxiety can be regarded as “something felt”, a specific unpleasant emotional state or condition that includes feelings of apprehension, tension, worry, and physiological arousal (Freud, 1936). Physiological arousal refers to increased heart rates, clammy hands, and other physical changes that we are probably all familiar with from hazardous situations, such as exams, public speaking, and an important sports match. The focus of the current thesis is on the situation-specific anxiety that occurs in these situations and which is called state anxiety (as opposed to trait anxiety which refers to anxiety as a personality characteristic) (e.g., Spielberger, 1966). State anxiety can cause people to perform worse than expected, causing them to stumble over their words during that important presentation or missing that decisive penalty during a soccer game.

Distraction theories

Distraction theories provide a theoretical explanation with regard to the mechanisms underlying performance decrements evoked by anxiety (e.g., Eysenck & Calvo, 1992; Eysenck, Derakshan, Santos, & Calvo, 2007; Kahneman, 1973). These theories propose that performance decrements occur because anxiety distracts attention away from information that is crucial for task performance. Attentional control theory (ACT, Eysenck et al., 2007) is a distraction theory developed within the domain of cognitive psychology. ACT builds on idea that functionally two attentional systems can be distinguished: a top-down, goal-directed system, and a bottom-up, stimulus-driven system (Corbetta & Shulman, 2002). With anxiety, the balance between the two systems is disrupted in favor of the stimulus-driven system. As a result, anxiety facilitates attention towards detecting the threat that causes the anxiety and thereby shifts attention away from task execution (Eysenck et al., 2007). In support of this proposition, Nieuwenhuys and Oudejans (2011), for example, found that police officers who were confronted with a threatening opponent who shot back at them with soap cartridges (high-anxiety), executed more and longer fixations to the opponent’s gun (a potential threat to task execution) than when the officers were confronted with an opponent who did not shoot back (low-anxiety). Moreover, in the high-anxiety condition, police officers paid less attention to the target area that they were supposed to hit. Besides external distracters (such as the opponent’s gun) also internal distracters, such as worries and disturbing thoughts, are suggested to consume attention that is otherwise invested in task execution (Eysenck et al., 2007). In sports, worries about failure are an often occurring phenomenon (Oudejans, Kuipers, Kooijman, & Bakker, 2011). Similarly for soldiers, the threat of an upcoming attack might cause a soldier to worry about the situation and its consequences.

These anxiety-evoked changes in attention can be detrimental to task efficiency and performance (e.g., Nieuwenhuys & Oudejans, 2011; Wilson, Wood, & Vine, 2009; Beilock & Carr, 2001). Decreases in task efficiency are for example assessed through increases in performance times (Eysenck et al., 2007). Investing more time in the same task can be considered less efficient. Decreases in task performance were encountered in a variety of tasks (e.g., in rifle shooting, Nieuwenhuys & Oudejans, 2011; in sports, Wilson et al., 2009a; 2009b; in mathematics, Beilock & Carr, 2001). However, increased levels of anxiety do not always result in performance decrements. Extra (mental) effort can be invested to compensate for the loss in performance (Eysenck et al., 2007). In other words, anxiety can also motivate to try harder. As a result, performance may be maintained or in some cases even improved.

In general, the degree to which task execution is affected by anxiety also depends on the degree to which task execution relies on working memory (Eysenck et al., 2007). Consequently, much anxiety research is concerned with cognitive tasks. People are considered to have limited attentional resources, and task execution suffers when this attentional capacity is exceeded (e.g., Wilson, 2008). Anxiety is suggested to compete over the available attentional resources with the tasks that are executed. In other words, with anxiety, task execution changes from a single-task to dual-task situation (e.g., Beilock & Carr, 2001). Consequently, tasks that rely heavily on working memory are expected to be more vulnerable to performance breakdown under anxiety than tasks that are controlled almost entirely independent of working memory (Eysenck & Calvo, 1992).

Explicit-monitoring theories

Concerning (perceptual)-motor performance, there is an alternative line of theories that has received much attention in the literature, namely explicit-monitoring theories (e.g., Baumeister, 1984; Beilock & Carr, 2001; Lewis & Lindner, 1997). Explicit-monitoring theories propose that performance decrements under anxiety occur because people redirect their attention towards the step-by-step execution of movements that are normally automated (e.g., Baumeister, 1984; Beilock & Carr, 2001; Lewis & Lindner, 1997). These theories are based on the general assumption that motor task execution becomes automated over practice (e.g., Brown & Carr, 1989). When a task is first learned, performance is slow and conscious attention is required for every performance step (e.g., Brown & Carr, 1989). Subsequently, over practice, task execution becomes automated and fast, and no longer demands conscious attention (e.g., Brown & Carr, 1989; Beilock & Carr, 2001; Lewis & Lindner, 1997). Explicit-monitoring theorists suggest that anxiety raises self-consciousness and increases conscious attention to the execution of the movement again (e.g., Beilock & Carr, 2001). Consequently, automated performance is disrupted and performance decrements are suggested to occur (e.g., Baumeister, 1984; Beilock & Carr, 2001; Lewis & Lindner, 1997).

In line with this contention, Gray (2004) for example, found that the instruction to pay attention to the direction of bat movement in a baseball batting task led to decreased experts' batting performance (Gray, 2004). However, in explicit-monitoring studies participants are always instructed to pay conscious attention to their movement execution (e.g., Gray, 2004; Gucciardi & Dimmock, 2008; Jackson, Ashford, & Norsworthy, 2006; Lam, Maxwell, & Masters, 2009). Therefore, it remained unclear whether explicit attention to movement execution naturally occurs in stressful situations. Recently, Oudejans et al. (2011) asked skilled performers to indicate their main focus of attention when performing under high pressure in competition. The skilled performers mainly consider their performance decrements to be due to distraction (such as worries about failure).

An integrated model of anxiety and (perceptual-motor) performance

Recently, Nieuwenhuys and Oudejans (2012) proposed that, instead of being mutually exclusive, distraction and explicit-monitoring theories might actually complement each other. Both lines of theory explain the effects of anxiety through changes in attention. Nieuwenhuys and Oudejans suggest that a focus on movement execution can also be regarded as a distraction away from task-relevant information. Thus, effects of anxiety can be explained through the same (distraction) principles in both types of theories. Consequently, Nieuwenhuys and Oudejans integrated the two existing frameworks into a model that explains the various ways in which anxiety can affect performance (see Figure 1.1). The model is largely based on ACT. It incorporates shifts from goal-directed to stimulus-driven processes due to anxiety, and the possibility to invest extra mental effort that is typical to ACT. Moreover, the model incorporates situational and dispositional factors (top left in Figure 1.1) which I will not explain any further as these factors are beyond the scope of the current thesis. More important, as can be seen on the right side of the model, the authors propose three levels at which anxiety can affect goal-directed performance: threat-related *attention*, threat-related *interpretation*, and threat-related *response tendencies*.

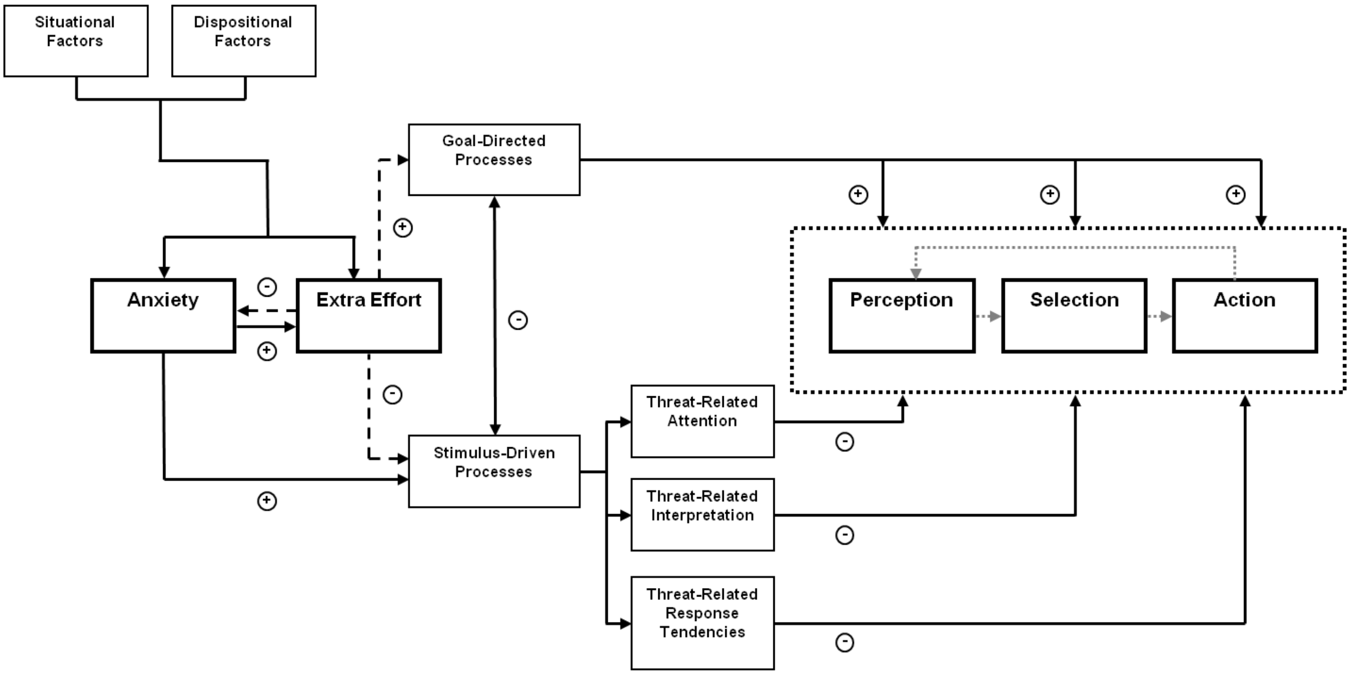


Figure 1.1. An integrated model of effects of anxiety on perceptual-motor performance (Nieuwenhuys & Oudejans, 2012).

On an *attentional level* (e.g., which information is picked up), anxiety is suggested to shift attention towards threat-related stimuli at the expense of attention directed at perceiving, selecting, and realizing possibilities for action. This proposition will be addressed in **Chapter 2 and 3**. Support for this proposition comes from studies that assessed gaze behavior under anxiety. These studies indicate that people who perceive themselves as anxious more often direct their visual attention towards threat-related stimuli and focus on target areas for shorter durations (for penalty kicks, Wilson et al., 2009b; skeet, Causer, Holmes, Smith, & Williams, 2011; handgun, Nieuwenhuys & Oudejans, 2010; and basketball shooting, Wilson et al, 2009a). Moreover, less efficient gaze behavior was often accompanied by reduced far aiming performance. It is argued that in these cases fixations at the target area were too short to pick up the information necessary for task performance. For an overview of previous findings on the effects of anxiety on (perceptual-motor) performance in the domains of sports and policing, see also Wilson (2008).

Second, on an *interpretational level* (e.g., how the environment is perceived), anxiety is suggested to cause people to misinterpret information on the basis of current feelings (cf. **Chapter 5**). In line with this suggestion, studies on decision making in policing for example indicate that police officers have an increased tendency to shoot surrendering suspects when under anxiety (Nieuwenhuys & Oudejans, 2011). The officers had a greater tendency towards interpreting an opponent to possess a gun even if they did not have one. Moreover, people tend to perceive information different when they are anxious. For example, people who perceived themselves as anxious because they were standing on a skateboard on top of a hill, perceived that hill to be steeper than people standing on a wooden box of the same height (Stefanucci, Proffitt, Clore, & Parekh, 2008).

Third, on a *response tendency level* (behavioral responses), anxiety is proposed to lead to changes in heart rate, blood pressure, breathing frequency, and energy expenditure. As a result, movements are proposed to become less efficient. **Chapter 2** examines this proposition in relation to a running task. Moreover, threatening stimuli facilitate specific behavioral responses, such as avoidance tendencies (e.g., Stins et al., 2011). Stins et al. showed that positive emotional cues (e.g., pictures of happy faces) evoked a tendency to move towards the stimulus (approach movements). Opposite, negative emotional cues (e.g., pictures of angry faces) evoked a tendency to move away from the stimulus (avoidance movements).

The military domain

Soldiers perform a variety of tasks. First, they need basic cognitive skills such as memory and math skills. Moreover, they must be able to sustain their attention over long periods of time (vigilance) and make accurate decisions (is this opponent hostile or friendly?). Second, soldiers require perceptual-motor skills for accurate shooting. Third, also tasks that rely on the aerobic system, such as walking and running, are important for infantry soldiers. As mentioned in the previous sections, an extensive body of literature already focused on the effects of anxiety on cognitive and perceptual-motor performance (e.g., Beilock & Carr, 2001; Eysenck et al., 2007; Nieuwenhuys & Oudejans, 2010; Oudejans, 2008; Wilson, 2008). However, it remains to be determined whether anxiety affects basic aerobic tasks that apply to the military, such as running.

Moreover, soldiers often have to perform several tasks simultaneously. They aim their weapon while concurrently calculating how many magazines they have left, repair equipment while staying vigilant, etc. One might expect the effects of anxiety on performance to be larger when two (or more) attention demanding tasks are combined. There are studies that support this suggestion for the concurrent performance of two cognitive tasks (e.g., Eysenck, Payne, & Derakshan, 2005). However, to date it is unclear how anxiety affects combinations of aiming and cognitive tasks. Moreover, dual-task performance might also be mediated by expertise level.

Expert shooters probably invest less attention in a shooting task than novice shooters and might therefore have more attentional resources available for quick calculations or to compensate for possible negative effects of anxiety. More research in this field is warranted to scrutinize the combined effects of anxiety, a secondary task, and expertise on operational performance and to gain more insight in whether effects accumulate or interact.

Finally, in addition to concurrent task performance, to date, little is known about the effects of multiple concurrent stressors on operational performance. Anxiety often is not the only stressor threatening soldier performance. Soldiers also have to deal with exertion from walking and running with heavy backpacks over rough terrain, and for extended periods of time. In the following section we will present the current state of the science with regard to exercise-induced fatigue before moving on to combinations of stressors.

Effects of exercise-induced fatigue on performance

Fatigue is a complex concept that has kept researchers puzzled for decades. The term fatigue has received a multitude of meanings and has been studied with regard to for example sleep deprivation, muscle fatigue, central fatigue, cognitive fatigue, and exercise-induced fatigue (e.g., Knicker, Renshaw, Oldham, & Cairns, 2011; Matthews, Desmond, Neubauer, & Hancock, 2012). Due to these differences in interpretation, a clear and overarching definition is lacking. Muscle physiologists, for example, describe fatigue as a reduction of muscle force and propose that this is what causes people to slow down. On the other hand, exercise scientists define fatigue as an exercise-induced performance decrement (Knicker et al., 2011). All of the different types of fatigue mentioned above are relevant for operational performance. However, in the current thesis, I narrowed down the focus to exercise-induced fatigue and its effects on cognitive and perceptual-motor performance.

What is exercise-induced fatigue? Traditionally, exercise was considered to be limited by a failure of homeostasis (e.g., Bainbridge, 1931; Bassett Jr. & Howley, 1997, 2000). It was believed that a person’s ability to perform maximal exercise is only determined by the heart’s capacity to pump enough blood to the active skeletal muscles. Accordingly, exercise is terminated when the oxygen demands of the active muscles exceed the limited capacity of the heart to supply this oxygen. When the capacity of the heart is exceeded, skeletal muscle anaerobiosis occurs and lactic acid accumulates in the muscles, eventually exercise is terminated. The higher the blood supply to the muscles, the greater the exercise intensity that can be achieved before the onset of anaerobiosis and fatigue, and thus the greater the ability to perform maximal exercise.

Recently, attention for exercise-induced fatigue as an emotion is increasing and performance effects are suggested to depend on how exerted people perceive themselves to be rather than a person’s actual oxygen supply (e.g. Noakes, 2012). According to Noakes’ (2012), exercise-induced fatigue “is part of a complex regulation, the goal of which is to protect the body from harm part. The brain uses the symptoms of fatigue as key regulators to insure that the exercise is completed before harm develops. These sensations of fatigue are unique to each individual and are illusionary since their generation is largely independent of the real biological state of the athlete at the time they develop” (Noakes, 2012, p. 2). In the current thesis, exercise-induced fatigue was induced through acute bouts of exercise. Changes in physiological measures (e.g., heart rate, oxygen uptake, gait parameters) as well as mental measures (rate of perceived exertion, RPE) were assessed to distinguish between the different physical states in which participants performed their tasks.

Arousal theories

The majority of studies investigating the relationship between exercise-induced fatigue and cognitive performance tested hypotheses derived from arousal theories (e.g., Lyons, Al-Nakeeb, & Nevill, 2006; McMorris et al, 1996a, 1996b; McMorris et al., 1999). Arousal theories propose that increases in exercise intensity are accompanied by an increase in physiological arousal (e.g., Kahneman, 1973; Sanders, 1986; Yerkes & Dodson, 1908). These increases in arousal are usually assessed through increases in for example heart rate or oxygen uptake. The arousal theory that is most often referred to is Yerkes and Dodson's (1908) inverted-U theory (see Figure 1.2). With a low arousal level, cognitive performance is expected to be low. When the arousal level increases, performance is expected to increase, up to an optimal level. As arousal continues to increase, performance is expected to gradually decline again.

Another arousal theory is Kahneman's (1973) multidimensional allocation of resources theory. According to Kahneman, cognitive performance depends not only on physiological arousal, but also on the allocation of mental effort to the execution of the task. It is suggested that people can invest extra mental effort in the task to optimize performance at low and moderate arousal levels. Performance is thus not necessarily low at low arousal levels as is predicted by the inverted-U hypothesis. Moreover, a person's attentional resources are suggested to be limited and at very high arousal levels this attentional capacity is exceeded. Consequently, insufficient attentional resources are allocated to the task leading to reduced performance, despite the extra effort invested. Insufficient attentional resources are also allocated to the task when high levels of arousal cause attention to be distracted towards irrelevant stimuli, such as sensations of discomfort and fatigue (McMorris & Keen, 1994).

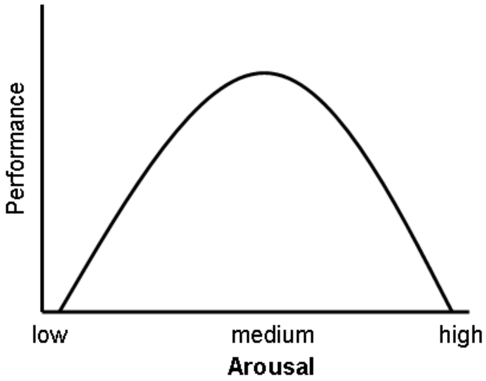


Figure 1.2. Inverted-U shaped relationship between arousal and performance by Yerkes and Dodson (1908).

A series of studies examined the predictions of arousal theories (for an overview, see Lambourne & Tomporowski, 2010). However, the heterogeneity of experimental design in previous research makes it difficult to compare the findings (e.g., Chang, Labban, Gapin, & Etnier, 2012). Effects of acute bouts of exercise are proposed to depend on for example the fitness level of the participant, the intensity and duration of the exercise protocol (< 20 min, > 20 min), the type of exercise (cycling, running), the timing of cognitive assessment (during or after exercise), and the type of (cognitive) task performed. Meta-analyses that took into account these possible moderators show a small, positive overall effect of acute bouts of exercise on cognitive performance, independent of exercise intensity (Chang et al., 2012; Lambourne & Tomporowski, 2010; McMorris & Hale, 2012). Although overall effects were not in line with arousal theories, negative effects on cognitive performance were found when cognitive tasks were performed during exercise as opposed to after exercise (Lambourne & Tomporowski, 2010). It is argued that these performance decrements are due to the dual-task condition that is created when participants have to perform the cognitive tasks while running or cycling. Lambourne and Tomporowski suggest that cycling, and especially running, consume attentional resources thereby leaving fewer resources available for cognitive performance. Moreover, support for arousal theories comes from findings with regard to participants' fitness level. Reduced cognitive task performance (during exercise) was especially prominent for participants with relatively low fitness (Chang et al., 2012). It can be argued that these participants need to invest more attentional resources in conducting exercise. Consequently, they are thought to have fewer resources available for cognitive performance (Chang et al., 2012).

Concerning perceptual-motor tasks such as shooting, research into effects of acute bouts of exercise is scarce. Generally, studies that focus on exercise-induced fatigue and perceptual-motor performance assess effects of muscle fatigue (e.g., stroke accuracy in table tennis, Aune, Ingvaldsen, & Ettema, 2008; in tennis, Davey, Thorpe, & Williams, 2002; in water polo shooting skill, Royal et al., 2006). The few studies that focus on fatigue induced through acute bouts of exercise are performed in the domain of biathlon (Grebot, Groslambert, Pernin, Burtheret, & Rouillon, 2003; Hoffman, Gilson, Westenburg, & Spencer, 1992; Vickers & Williams, 2007). These studies implicate that intense exercise can negatively affect shooting performance, especially for shooting in a standing position. The reasons for these performance decrements to occur remain underexposed. However, there are indications of an inverted-U shaped relation between exercise-induced fatigue and accuracy in biathlon shooting. Vickers and Williams (2007) assessed that biathlon athletes shot more accurately after exercising at 55% of maximum oxygen uptake than during the non-exercise pretest. Subsequent higher levels of oxygen uptake (up to 100%) were again accompanied by declines in shooting accuracy.

Gradually increasing exercise-induced fatigue

The working environment of soldiers is characterized by long periods of relatively low-level physical activity interspersed with periods of high-intensity activities such as running. During these high-intensity periods, exercise-induced fatigue typically increases progressively, for example, during pursuit of enemy. Although studies indicate that cognitive and shooting performance can alter during or after an acute bout of exercise, to date, it remains unknown how these changes gradually evolve as exercise-induced fatigue increases (e.g., Lambourne & Tomporowski, 2010; Vickers & Williams, 2007). Most studies that investigated the effect of exercise-induced fatigue on decision making and shooting accuracy compared performance at resting levels with only one or two intensity levels. As a result, the precise intensity level at which skill accuracy significantly declines cannot be determined. However, for soldiers, the ability to maintain accurate decision making and perceptual-motor performance (such as shooting) even during the final stages of a military mission is crucial to performance. Similarly, Barr, Gregson, and Reilly (2010) concluded in a recent review that decision making in first responders, more specifically fire brigades, is one of the most important issues that should be addressed to improve their operational performance. Therefore, in **Chapter 4** we designed a pursue-and-shoot task to examine shooting decisions with increasing exercise-induced fatigue.

Multi-tasking and combined effects of anxiety and exercise-induced fatigue

Since anxiety and exercise-induced fatigue co-exist in operational performance, more research on the combination of both stressors is required. Moreover, while coping with multiple stressors, generally, several tasks have to be performed simultaneously. Soldiers, for example, have to be able to sustain attention to environmental stimuli and communications equipment. Success on the battlefield will depend on how well they are able to do this while simultaneously walking or running and while being physically exerted and anxious. Dealing with multiple stressors and concurrent task performance makes investigating operational performance complex. It remains to be discovered whether these factors, and their consequent performance effects, add up, or whether they interact.

In addition, recent studies emphasize the need for more realistic experiments that investigate these themes. Results of laboratory-based studies appear insufficient to simulate the demands encountered in naturalistic human performance environments (Dicks, Button, & Davids, 2010; Lambourne & Tomporowski, 2010; Mann, Williams, Ward, & Janelle, 2007). Therefore, the series of experiments in this thesis is concluded with a field study that incorporates multiple tasks and stressors (see **Chapter 5**).

To summarize, although effects of anxiety on cognitive and perceptual-motor tasks have been examined in great detail, the effects of anxiety on the basic aerobic task of running have been left unattended. Moreover, there is still little attention to how effects of exercise develop as exercise-induced fatigue gradually increases. Finally, literature on the combined effects of anxiety and fatigue and the effects of these stressors on combinations of cognitive and (perceptual-)motor tasks is virtually non-existent. More research is needed to scrutinize the effects of anxiety and exercise-induced fatigue on operational performance, especially in test environments that closely resemble military practice.

Human performance modeling

The development of computer simulations allows us to predict human performance under circumstances that are hard or impossible to create in an experimental setting. Studies on the nature and severity of performance decrements on the battlefield are practically non-existent due to the high risk of injury (or death) and the presence of actual casualties on the battlefield (Lieberman et al., 2005). Therefore, especially for the harsh military environment simulations provide a useful tool. In **Chapter 6**, the results of the experiment in **Chapter 2** are used to provide a first step in the validation and improvement of the CHAOS (Capability-based Human-Performance Architecture for Operational Simulation) architecture (see Figure 1.3). The

CHAOS architecture incorporates human behavior and performance models in order to simulate operational performance of the soldier or the rapid responder (see Figure 1.4).

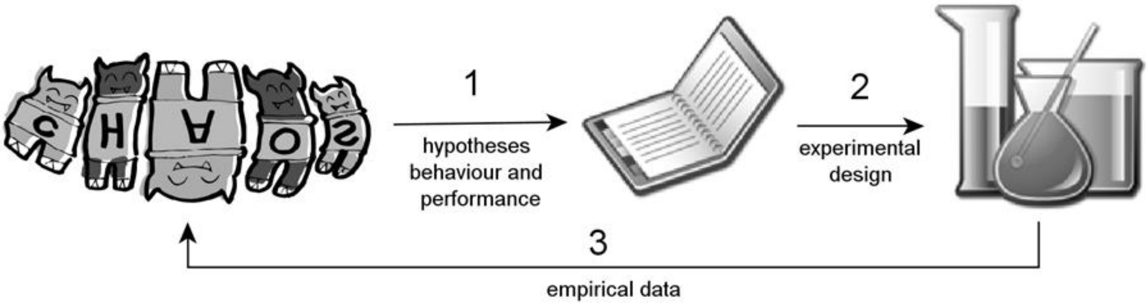
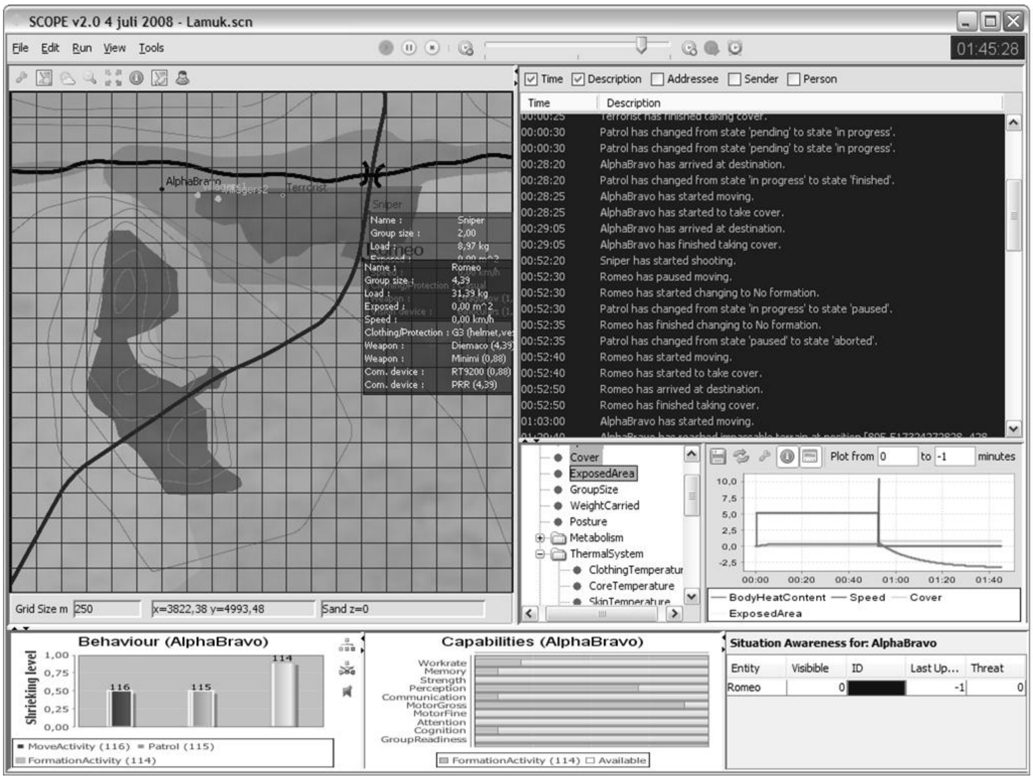


Figure 1.3. CHAOS validation cycle: the mechanisms in CHAOS form the hypotheses on which the experiments are based. The empirical data from the experiments is then used to build a simulation model in CHAOS. This allows us to check if the mechanisms in CHAOS can support the empirical results that were found.



Name : Sniper
Group size : 2,00
Load : 8,97 kg

Name : Romeo
Group size : 4,39
Load : 31,39 kg
Exposed : 0,00 m^2
Speed : 0,00 km/h
Clothing/Protection : G3 (helmet,ve
Weapon : Diemaco (4,39)
Weapon : Minimi (0,88)
Com. device : RT9200 (0,88)
Com. device : PRR (4,39)

Grid Size m 250
x=3822,38 y=4993,48
Sand z=0

☑ Time ☑ Description ☐ Addressee ☐ Sender ☐ Person

```
Time       Description
00:00:25   Terrorist has finished taking cover.
00:00:30   Patrol has changed from state 'pending' to state 'in progress'.
00:00:30   Patrol has changed from state 'pending' to state 'in progress'.
00:28:20   AlphaBravo has arrived at destination.
00:28:20   Patrol has changed from state 'in progress' to state 'finished'.
00:28:25   AlphaBravo has started moving.
00:28:25   AlphaBravo has started to take cover.
00:29:05   AlphaBravo has arrived at destination.
00:29:05   AlphaBravo has finished taking cover.
00:52:20   Sniper has started shooting.
00:52:30   Romeo has paused moving.
00:52:30   Romeo has started changing to No formation.
00:52:30   Patrol has changed from state 'in progress' to state 'paused'.
00:52:35   Romeo has finished changing to No formation.
00:52:35   Patrol has changed from state 'paused' to state 'aborted'.
00:52:40   Romeo has started moving.
00:52:40   Romeo has started to take cover.
00:52:50   Romeo has arrived at destination.
00:52:50   Romeo has finished taking cover.
01:03:00   AlphaBravo has started moving.
```

Plot from 0 to -1 minutes

Situation Awareness for: AlphaBravo

Entity	Visibile	ID	Last Up...	Threat
Romeo	0	■	-1	0

Figure 1.4. Screenshot of a simulation in CHAOS. Top left: map of the operational environment. Top right: programming language. Lower half: distribution of the resources between the types of behavior that are required to perform the mission.

Stressors & multi-tasking

The assumptions in the CHAOS architecture are similar to the central tenets of attentional control theory (ACT, Eysenck et al., 2007). In line with ACT, CHAOS distinguishes goal-directed and stimulus-driven behavior. Moreover, in CHAOS a central part is played by resources, of which ACT's attention is a specific example. Also, CHAOS allows for the inclusion of stressors (such as anxiety and exercise-induced fatigue) and multi-tasking. Stressors as for example exercise-induced fatigue or exhaustion can be modeled in separate (in this case physiological) models. CHAOS integrates these stressors to affect performance and behavior. For example, exhaustion (stressor) consumes the resources necessary for walking and exploring the environment. As a result soldiers will slow down and eventually stop their activity. Only when the soldiers have rested sufficiently and resources are restored again the soldiers will continue their mission.

Moreover, CHAOS indicates that some processes rely on the same resources, which makes it possible to model multi-tasking. Concerning multi-tasking there are three options:

1. Selective multi-tasking, where the process with the highest priority consumes all resources and no resources are left for other activities.
2. Sub-optimal multi-tasking, where two tasks will be executed simultaneously but performance on one or both tasks will be impaired.
3. Optimal multi-tasking, where enough resources are available and several tasks can be executed at the same time without interfering with each other.

The final operational performance of the soldier follows from the interaction between behavior and the other (e.g., physiological) models.

The assumptions underlying CHAOS are not far-fetched and in line with common sense. Furthermore, previous applications of CHAOS in simulations in the military, fire-fighting, and traffic domains, provided results with good face validity (e.g., Ubink et al., 2008). However, a scientific underpinning of the assumptions is lacking. Therefore, a second aim of the current thesis is to provide a first step into validating the CHAOS architecture. Thereto, a model will be implemented into the architecture and the outcome of the model will be compared with empirical results (see **Chapter 6**).

Scope & outline of the thesis

In the current thesis, we aimed to further our understanding of the separate and combined effects of anxiety and exercise-induced fatigue on tasks, and combinations of tasks, that apply to operational performance. We considered perceptual-motor and cognitive tasks, as well as tasks that rely heavily on the aerobic system, such as running. In the **Chapters 2-4**, we aimed to investigate the basic constructs. These studies comprised laboratory-based experiments and did not include infantry soldiers. More precisely, the first two experiments were designed to assess effects of anxiety on task performance. In **Chapter 2**, we explored whether anxiety, next to affecting cognitive and perceptual-motor tasks, can also affect tasks that rely heavily on the aerobic system. To that aim, participants' running efficiency was assessed in a low- and high-anxiety condition. Moreover, as aiming tasks, such as shooting, are often combined or interchanged with physical exertion, effects of anxiety on running combined with a far aiming task (in this case dart throwing) were assessed in the last minutes of the running task.

Shooting is also often combined with cognitive tasks. Soldiers have to be able to perform quick calculations, for instance how many magazines they have left when firing at the enemy. Moreover, expertise also mediates a person's performance in aiming tasks. Therefore, in **Chapter 3**, we investigated whether and how anxiety, a cognitive secondary task, and expertise influenced far aiming performance. To that aim novice and expert dart players performed a dart task low (low-anxiety) and high (high-anxiety) on a climbing wall and with and without a concurrent counting backwards task. To assess possible changes in attention due to the manipulations, participants' gaze behavior was registered as a measure of visual attention.

Subsequently, in **Chapter 4** we investigated whether and how people's behavior is affected when exercise-induced fatigue gradually increases. Until now research into the effects of exercise-induced fatigue usually considered one or two fatigue levels. However, soldiers' working environment is characterized by periods of high-intensity activities such as running, where exercise-induced fatigue typically increases progressively. Therefore, we assessed participants' shooting decisions during a pursue-and-shoot task. Exercise-induced fatigue gradually increased as participants ran on a treadmill and pursued and shot at a target in a virtual environment.

We concluded our series of experiments with a military field study in **Chapter 5**. We assessed the effects of anxiety and exercise-induced fatigue in infantry soldiers that performed a field track that was set-up in a military practice village. The field track comprised a series of cognitive (e.g., mathematics, vigilance, and decision making) and shooting tasks inside and around a military practice house. Then, in **Chapter 6**, a selection of the results from **Chapter 2** was implemented in the CHAOS architecture as a first step in the validation of the architecture. Finally, **Chapter 7** (the Epilogue) provides a brief summary and discusses the main results in this thesis. Theoretical and practical implications are discussed, along with recommendations for future research.

Chapter 1

2

Effects of anxiety on running with and without an aiming task

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Abstract

State anxiety is known to affect far aiming tasks, but less is known about the effects of state anxiety on running and aiming while running. Therefore, in the current study participants ran on a treadmill at their preferred speed in a low- and high anxiety condition. In both conditions, running was combined with dart throwing in the last minutes. Results showed that attention shifted away from task execution with elevated levels of anxiety. Furthermore, gait patterns were more conservative and oxygen uptake was higher with anxiety. In addition, performance and efficiency on the dart throwing task also decreased with anxiety. These findings are in line with attentional control theory and provide an indication that state anxiety not only affects aiming tasks but also tasks that rely heavily on the aerobic system. Moreover, findings indicate that when combined, running, aiming, and anxiety all compete for attention leading to suboptimal attentional control and possibly a decrease in performance.

Keywords: aerobic exercise, attentional control theory, dart throwing, gait, perceptual-motor tasks

Introduction

In competitive sport and other high-achievement settings, humans often experience high anxiety, which may affect their task execution and performance. A theory that provides an explanation for the mechanisms behind the effects of state anxiety on task execution is attentional control theory (Eysenck et al., 2007), a recent extension of processing efficiency theory (PET; Eysenck & Calvo, 1992). Attentional control theory proposes that there are two attentional systems: a top-down, goal-directed system, and a bottom-up, stimulus-driven system (Corbetta & Shulman, 2002). With anxiety, the balance between the two systems is disrupted in favor of the stimulus-driven system. As a result, anxiety facilitates attention towards detecting the threat that causes the anxiety and thereby shifts attention away from task execution (Eysenck et al., 2007). Such shifts in attention can lead to a decrease in task efficiency, and possibly performance, as less attention is available for actual task execution. As an example, penalty kick performance in soccer players deteriorated when state anxiety was induced (Wilson et al., 2009b). In line with attentional control theory, this drop in performance was accompanied by shifts in visual attention from the goal target area towards the goalkeeper, which is a potential threat to scoring a penalty in soccer.

According to attentional control theory, anxiety does not necessarily lead to a decrease in performance. It is suggested that negative effects of anxiety can be compensated for by the investment of additional attentional resources and extra mental effort. As a result, efficiency of task execution (called processing efficiency) decreases but performance may be maintained. For example, it was shown for rally driving (Wilson, Chattington, Marple-Horvat, & Smith, 2007) and volleyball (Smith, Bellamy, Collins, & Newell, 2001) that people invested more mental effort when they were anxious (showing a decrease in processing efficiency) yet performance was maintained.

Whether task execution is affected by anxiety depends on the degree to which task execution relies on working memory (Eysenck et al., 2007). Tasks that rely heavily on working memory are expected to be more vulnerable to performance breakdown than tasks that are controlled almost entirely outside of working memory (Eysenck & Calvo, 1992). Much research on attentional control theory is concerned with cognitive tasks, as these often rely heavily on working memory. However, findings that support attentional control theory are available for perceptual- motor aiming tasks such as penalty kicks (Wilson et al., 2009b), skeet (Causer et al., 2011), handgun (Nieuwenhuys & Oudejans, 2010), and basketball shooting (Wilson et al., 2009a). Yet, many of the sports in which aiming tasks are important, such as soccer, basketball, and handball, also contain a large aerobic component; that is, many of these tasks are combined or interchanged with physical exertion often in the form of running. Whether and how state anxiety affects running and far aiming while running remains unclear. Therefore, in the current study we investigated the effects of anxiety on running alone and on running combined with dart throwing.

For running, movement control is generally viewed as highly automated with marginal use of cognitive resources (Hausdorff, Yogev, Springer, Simon, & Giladi, 2005). However, a growing body of literature indicates that walking and running do address attentional resources. Lindenberger and colleagues (Lindenberger, Marsiske, & Baltes, 2000) tested participants performing a memory task while walking, while sitting, and while standing. Performance on the memory task decreased during walking compared with sitting and standing. Also, more missteps (steps outside the outlined walking track) were made when walking was combined with the memory task. Furthermore, in several other studies, stride frequency was found to increase (Ebersbach, Dimitrijevic, & Poewe, 1995) and stride length to decrease (Nadkarni, Zabjek, Lee, McIlroy, & Black, 2010; Yang, Chen, Lee, Cheng, & Wang, 2007) when walking was combined with a secondary cognitive task. Apparently, although highly practiced, gait is not completely automated and still demands attention (cf. Abernethy, Hanna, & Plooy, 2002). If running, just as walking, also requires attention, and state anxiety disturbs attentional control, then one would expect state anxiety to also affect running efficiency.

Regarding the effects of anxiety, Brown and colleagues (Brown, Doan, McKenzie, & Cooper, 2006) provided support for this suggestion for walking. They imposed anxiety by manipulating imbalance when participants walked on a walkway. This manipulation consisted of elevating the walkway, reducing the width of the walkway, and a combination of the two. Brown et al. observed that stride and step length reduced with anxiety and concluded that with anxiety participants adopted a more conservative gait pattern to reduce the risk of falling. To date, few researchers have investigated the relationship between state anxiety and the aerobic demands of running. Martin and colleagues (Martin, Craib, & Mitchell, 1995) investigated the relationship between oxygen uptake and trait rather than state anxiety of 18 competitive distance runners during sub maximal treadmill running. No correlation was found between trait anxiety and oxygen uptake. Acevedo and colleagues (Acevedo, Dzewaltowski, Kubitz, & Kraemer, 1999) did manipulate state anxiety with a challenging video while trained endurance runners ran on a treadmill at sub maximal speed. No effect of anxiety on oxygen uptake was found. However, an increase in anxiety was only visible for a short period at the beginning of the anxiety condition, suggesting that participants performed most of the anxiety condition under an anxiety level that was comparable to that of the no-anxiety condition. In short, as Martin et al. (1995) did not investigate state anxiety and Acevedo and colleagues' (1999) manipulation of state anxiety had methodological limitations, the question whether state anxiety affects running remains unanswered. Nonetheless, several studies have shown that the aerobic system can be influenced by psychological factors, such as relaxation and attentional focus (Caird, McKenzie, & Sleivert, 1999; Eaves, Hodges, & Williams, 2008; Martin et al., 1995; Schücker, Hagemann, Strauss, & Volker, 2009). Schücker et al. (2009), for instance, found that different foci of attention (internal or external) during running led to differences in oxygen uptake. Similarly, Eaves et al. (2008) found that running under different conditions of visual attention (dynamic mirror image, dynamic reversed mirror image, and a static image) led to differences in running kinematics and oxygen uptake. In short, although there are indications that anxiety affects walking and that psychological factors such as attentional focus may affect running, the direct effects of state anxiety on running still need to be investigated.

In the current study, we had participants run and throw darts while running in two anxiety conditions, high and low above the ground. Height has previously been applied successfully to induce anxiety (e.g. Nieuwenhuys et al., 2008; Pijpers, Oudejans, & Bakker, 2005). To get an indication of whether changes in attention occurred with anxiety, participants provided retrospective verbal reports about their attentional focus during both anxiety conditions. Furthermore, we measured running efficiency. Running efficiency is commonly operationalized by running economy, which is defined as the energy demand for a given velocity of sub maximal running (Daniels, 1985). An individual who runs at the same speed as another individual but consumes less oxygen is said to run more efficiently. We also measured gait parameters that can provide additional indications of running efficiency. Saunders and colleagues (Saunders, Pyne, Telford, & Hawley, 2004) argued that running economy at a certain speed is the highest at a runner's self-selected stride length, and that oxygen uptake increases when the runner's stride length becomes either longer or shorter. Finally, we measured efficiency and performance of dart throwing.

Following attentional control theory, anxiety is predicted to shift attention away from running (and dart throwing) towards threat-related stimuli (e.g. worries; Eysenck et al., 2007). To compensate for this possible shift in attention, participants are expected to invest more mental effort in an attempt to remain focused on the task (Eysenck et al., 2007). Due to these changes in efficiency, we expected alterations in gait parameters and running economy (Brown et al., 2006; Schücker et al., 2009). More specifically, with anxiety, stride length is expected to decrease, while stride frequency and oxygen uptake are expected to increase (Ebersbach et al., 1995; Nadkarni et al., 2010). Perceived physical effort is expected to be higher with anxiety due to changes in gait parameters and running economy. Performance on the dart throwing task is expected to decrease and dart times are expected to increase with anxiety (Oudejans & Pijpers, 2009, 2010). Finally, as both anxiety and dart throwing are expected to consume attention, and thus evoke changes in gait parameters and running economy, we expect the changes in these parameters to be largest when running is combined with both dart throwing and anxiety.

Method

Participants

A total of 19 students (11 women, 8 men) with a mean age of 21.6 years (*SD* = 1.2) participated in the study. They were informed of the procedures of the experiment and they all provided informed consent prior to participation. The local ethics committee approved the experimental protocol. The participants completed the Dutch version of the A-trait scale of the State–Trait Anxiety Inventory (STAI; Van der Ploeg, Defares, & Spielberger, 1980). The mean trait score for the women (mean = 34.8, *SD* = 6.1) was not significantly different from the mean score for Dutch female students (mean = 37.7; Van der Ploeg et al., 1980) ($t_{10} = 1.57$, $p = 0.147$). The mean trait score for men (mean = 28.4, *SD* = 4.0) was significantly lower than the mean score for Dutch male students (mean = 36.1; Van der Ploeg et al., 1980) ($t_7 = 5.51$, $p = 0.001$). These scores imply that the participants were normal to low in trait anxiety and therefore had no extraordinary tendency to respond across many situations with high state anxiety. All participants had experience with treadmill running. Participants had no experience with dart throwing or performing at height.

Study design

All measurements were carried out on the same day. The study consisted of two conditions (low and high anxiety) of 10 min each with 10 min rest between conditions. Before the two experimental conditions, participants ran for 10 min on a treadmill (which was placed on a platform on the floor) and threw 12 practice darts three times to become accustomed to treadmill running and the aiming task and to determine their preferred running speed. This predetermined speed would be the participants' constant running speed throughout the experiment. Exercise of 15 min duration on a treadmill has been shown to be sufficient to accommodate to treadmill running (Schieb, 1986; Wall & Charteris, 1980, 1981). The accommodation time was reduced to 10 min in our study since all participants had experience with treadmill running. After the accommodation period, participants ran for 10 min at the predetermined constant speed in the low-anxiety and high-anxiety condition in a counterbalanced design. In both conditions, participants ran for 8 min (run phase) followed by a combined running and dart throwing phase (dart phase) during which they threw 12 darts.

Materials and measures

Anxiety manipulation

Anxiety was manipulated through height. Two identical small and narrow motorized treadmills (Bremshey Sport Path treadmill, length = 175 cm, width = 75 cm) were placed on a platform 20 cm above the ground and on a narrow scaffold (Upright Ireland, length = 200 cm, width = 80 cm) 4.2 m above ground level (see Figure 2.1). The arm rails were removed from the treadmills and the scaffold. In both conditions, the participants wore a full-body safety harness. In the high-anxiety condition, the harness was attached to a coupling that was anchored to the ceiling above the scaffold to prevent falling. In the low-anxiety condition, the safety harness was anchored to a batten, which was fixed on the scaffold. In both conditions, an emergency stop was attached to the harness that caused the treadmill to stop when participants moved too far to the rear end of the treadmill.

Subjective measures

After each condition, participants completed a 10 cm continuous visual-analogue scale to measure the anxiety experienced during that condition. The anxiety scale ranges from 0 (‘‘not at all anxious’’) to 10 (‘‘extremely anxious’’). The anxiety scale, also called the ‘‘anxiety thermometer’’, was validated by Houtman and Bakker (1989) and has been successfully used previously (e.g. Nieuwenhuys & Oudejans, 2010). Each individual was provided with a new scale after each condition. Although the anxiety thermometer does not differentiate between cognitive and somatic anxiety, Bakker and colleagues (Bakker, Vanden Auweele, & Van Mele, 2003) showed that anxiety thermometer scores correlate equally with the cognitive and somatic anxiety scores on the CSAI-2. Zijlstra's (1993) Rating Scale of Mental Effort (RSME) was used to assess the amount of mental effort participants perceived they had invested in the running task. This vertical scale ranged from 0 (‘‘absolutely no effort’’) to 150 mm (‘‘most effort ever’’). The

RSME was shown to be valid and reliable by Veltman and Gaillard (1993) and has been used successfully previously (e.g. Eaves et al., 2008). The Dutch translation of the Borg Scale (Borg, 1982) was used to measure participants' ratings of perceived exertion (RPE). The Borg Scale ranges from 0 to 10, with 0 reflecting total rest and 10 corresponding to maximal perceived exertion.

Attentional focus

After the experiment, participants were asked to write down where they focused attention during both running conditions. Following Oudejans and colleagues (Oudejans et al., 2011), statements on attentional focus were selected from the verbal reports and then grouped into five categories: movement execution, distracting thoughts and worries, external task-relevant (e.g. statements concerning the treadmill or the dartboard), external task-irrelevant (e.g. statements concerning noises in the background), and positive monitoring (statements such as: ''I try to score as high as possible''). The statements about where participants focused their attention were analyzed and grouped by two independent observers. The inter-observer reliability was 90%.

Metabolic measures

Respiratory gases and heart rate were analyzed using the K4 system (COSMED, Rome, Italy). Running economy, defined as whole body energy expenditure at standard sub maximal speeds (O2 consumption in $\text{mL} \cdot \text{min}^{-1}$), was determined. To ensure that energy expenditure (and therefore running efficiency) was not compromised by anaerobic exercise, the respiratory exchange ratio (RER) was not allowed to exceed 1.00 (McArdle, Katch, & Katch, 2006, p. 243).

Kinematic measures

Gait parameters were measured using two foot switches (MA-153 event switches, Motion Lab Systems, Baton Rouge, LA) that were connected to an EMG recording system (Porti 17, Twente Medical Systems; 500 Hz sample rate). The switches were attached with duct tape under the heel and toe of the left shoe of the participant and were not removed between conditions. Contact time (time between initial heel contact and toe-off), stride frequency, and stride length (running speed divided by stride frequency) were determined from the heel strike and toe-off data.

Dart task

In the dart throwing phase, one dart board (diameter = 0.46 m) was used in both conditions. The dart board was attached at the official competition height and distance (1.74 m above running surface, throw line at about 2.37 m from the dart board) and could be moved from the low to the high condition and vice versa. The dartboard contained ten black and white circles varying in points. Bull's eye corresponded to 10 points. The score decreased by 1 point per circle when moving away from the bull's-eye. The darts were placed in a cup that was attached to the treadmill near the participants' dominant hand. No points were assigned for darts that missed the board. Participants were instructed to throw 12 darts and to score as many points as possible. A ‘‘beep’’ provided by the experimenter announced the start of the dart throwing phase. Participants took the darts from the cup one dart at a time. The average score per dart was calculated as a measure of performance. Dart efficiency was assessed through dart time, which was defined as the amount of time the participant took to throw the 12 darts.

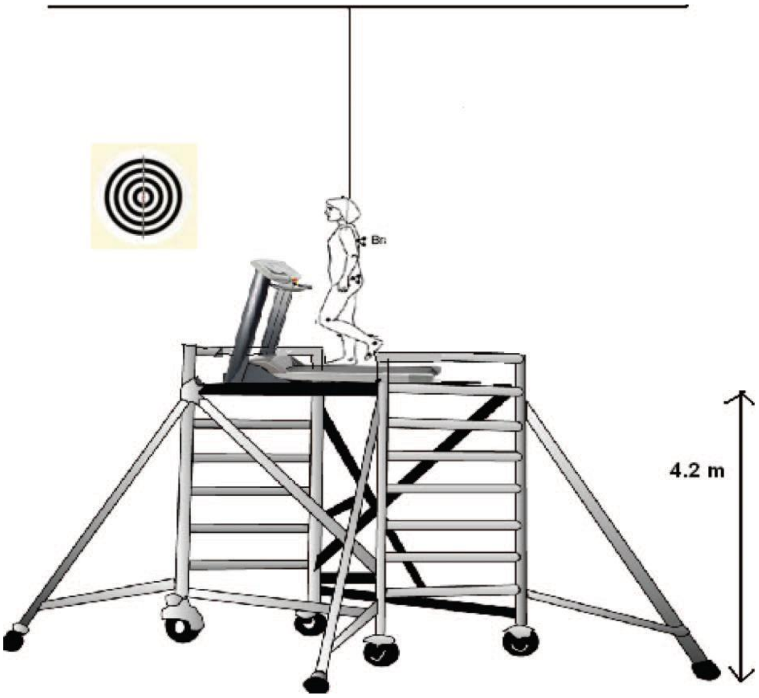

Figure 2.1. Experimental set-up of the high-anxiety condition.

Procedures

Upon arrival, participants were informed of the procedures. They gave their written informed consent and completed the STAI. Foot switches were attached to their left shoe, the K4 was put on, and participants’ baseline heart rate was measured. Then, participants took position on the low treadmill and the accommodation condition started. Participants ran for 10 min, chose their preferred speed, and practiced dart throwing. After the accommodation condition, participants sat down on a chair and rested until their heart rate had returned to baseline values. Subsequently, participants took position on the treadmill for either the low-anxiety or high-anxiety condition. The scaffold in the high-anxiety condition was reached by a 5 m high mobile footbridge. Participants were fitted with the safety harness and started their first running condition. They ran at their predetermined speed and after 8 min a ‘‘beep’’ announced the start of the dart throwing phase. Participants threw 12 darts. Dart times and dart scores were recorded. At the end of a condition, speed was slowly reduced to 0 km · h^{-1}. Participants immediately completed the anxiety thermometer, RSME, and Borg scale. Then, they stepped off the treadmill and sat down. Between conditions, participants rested for 10 min to ensure that their heart rate returned to baseline values. After the last condition, they completed the report about the focus of attention during running.

Data analysis

Chi-square tests were performed on the number of statements on attentional focus per category in the low-anxiety and high-anxiety condition. Furthermore, two-tailed paired *t*-tests were performed to assess the effects of condition (low anxiety, high anxiety) on anxiety scores, mental effort scores, RPE, dart scores, and dart time. Gait parameters, oxygen uptake, and heart rate were submitted to 2 x 2 (Condition [low anxiety, high anxiety] x Phase [run, dart]) repeated-measures analyses of variance.

Results

Table 2.1 provides an overview of the mean values (and standard deviations) of the main variables.

Manipulation check

Participants reported significantly more anxiety in the high-anxiety than in the low-anxiety condition ($t_{18} = 5.94$, $p < 0.001$, $d = 1.36$, 95% CI [2.2, 4.7]). Perceived mental effort was also significantly higher in the high-anxiety than in the low-anxiety condition ($t_{18} = 2.41$, $p = 0.027$, $d = 0.55$, 95% CI [1.9, 27.3]). Average RPE did not differ between conditions ($t_{18} = 0.83$, $p = 0.415$).

Attentional focus

The numbers and percentages of the statements on attentional focus are listed in Table 2.2. Attentional focus was significantly different in the low-anxiety than in the high-anxiety condition ($\chi^2(12) = 153.0$, $p < 0.001$). Worry and distracting thoughts were mentioned significantly more often in the high-anxiety than in the low-anxiety condition ($\chi^2(1) = 6.533$, $p = 0.011$).

Table 2.1. Mean values (and standard deviations) for perceived effort, exertion and anxiety, dart performance, oxygen uptake, heart rate, and gait parameters during treadmill running in low- and high-anxiety conditions.

	Condition	
	Low Anxiety	High Anxiety
	M (SD)	M (SD)
Anxiety Thermo***	1.4 (1.1)	4.8 (2.2)
RSME*	44.1 (26.6)	58.6 (21.8)
RPE	3.3 (1.6)	3.5 (1.3)
O_2 Uptake (ml min^{-1})*		
run phase	2240 (256)	2297 (280)
dart phase	2391 (263)	2464 (326)
HR (bpm)*		
run phase	161.7 (17.6)	166.9 (15.5)
dart phase	169.6 (16.8)	173.3 (14.0)
F_{stride} (stride min^{-1})***		
run phase	77.2 (4.3)	78.1 (4.3)
dart phase	77.6 (4.5)	79.2 (4.2)
L_{stride} (cm)***		
run phase	157.3 (11.3)	155.2 (10.7)
dart phase	156.3 (10.8)	152.9 (9.4)
$T_{contact}$ (ms)**		
run phase	287.0 (37.1)	298.0 (37.8)
dart phase	291.9 (34.1)	306.5 (40.4)
Dart Score (per dart)*	5.2 (1.1)	4.6 (1.6)
Dart Time (s dart^{-1})**	4.5 (1.1)	5.0 (1.3)

*Note. RSME = Rating Scale of perceived Mental Effort, RPE = Rating of Perceived Exertion, HR = heart rate, F_{stride} = stride frequency, L_{stride} = stride length, $T_{contact}$ = contact time, *p < .05; **p < .01; ***p < .001.*

Gait parameters

Recording of the toe-off data failed for five participants. Therefore, contact times could not be determined for these participants. There was a significant main effect of condition on stride frequency ($F_{1,18} = 26.28$, $p < 0.001$, $\eta_p^{2} = 0.60$), stride length ($F_{1,18} = 26.14$, $p < 0.001$, $\eta_p^{2} = 0.59$), and contact time ($F_{1,13} = 19.18$, $P = 0.001$, $\eta_p^{2} = 0.60$). Stride frequency was higher in the high-anxiety condition (1.3 strides ·min^{-1}, 95% CI [0.8, 1.9]), whereas stride length was shorter (2.7 cm, 95% CI [1.6, 3.9]) and contact time longer (12.8 ms, 95% CI [6.5, 19.1]) in the high-anxiety condition (see Table 2.1). There was also a significant main effect of phase on stride frequency ($F_{1,18}$ = 7.03, p = 0.016, $\eta_p{}^2$ = 0.28), stride length ($F_{1,18}$ = 7.46, p = 0.014, $\eta_p{}^2$ = 0.29), and contact time ($F_{1,13}$ = 10.60, p = 0.006, $\eta_p{}^2$ = 0.45). Stride frequency was higher in the dart throwing phase (0.8 strides · min^{-1}, 95% CI [0.2, 1.4]), whereas stride length was shorter (1.7 cm, 95% CI [0.4, 2.9]) and contact time longer (6.7 ms, 95% CI [2.2, 11.1]) in the dart throwing phase (see Table 2.1). There were no significant interactions.

Running economy and heart rate

Participants' average running speed was 7.3 km · h^{-1} (range: 7.0–7.8 km · h^{-1}). Their respiratory exchange ratio (RER) remained below 1.00 (mean = 0.91, s = 0.05), indicating that all participants exercised predominantly in the aerobic domain. In the run phase, mean values for oxygen uptake and heart rate were calculated for minutes 3 to 8. The first 2 min were excluded since the participants were trying to optimize their equilibrium during this starting phase (Schücker et al., 2009).

For oxygen uptake there were significant main effects of condition ($F_{1,18}$ = 5.55, p = 0.030, $\eta_p{}^2$ = 0.24) and phase ($F_{1,18}$ = 62.31, p < 0.001, $\eta_p{}^2$ = 0.78). Oxygen uptake was higher in the high-anxiety condition (65 mL · min^{-1}, 95% CI [7.1, 123.5]) and in the dart throwing phase (159 mL · min^{-1}, 95% CI [116.9, 201.6]) (see Table 2.1). There was no significant interaction.

Recordings of heart rate failed for two participants. For the remaining participants, heart rate showed significant main effects of condition ($F_{1,15}$ = 6.55, p = 0.022, $\eta_p{}^2$ = 0.30) and phase ($F_{1,15}$ = 27.28, p < 0.001, $\eta_p{}^2$ = 0.65). Heart rate was higher in the high-anxiety condition (4.1 beats · min^{-1}, 95% CI [0.7, 7.5]) and in the dart throwing phase (6.6 beats · min^{-1}, 95% CI [3.9, 9.2]) (see Table 2.1). There was no significant interaction.

Dart scores and dart time

Dart scores were significantly lower in the high-anxiety than in the low-anxiety condition (t_{18} = 2.26, p = 0.036, d = 0.52, 95% CI [0.1, 1.1]). Dart times were significantly longer in the high-anxiety than in the low-anxiety condition (t_{18} = 2.94, p = 0.009, d = 0.67, 95% CI [0.2, 0.9]).

Table 2.2. Numbers and percentages of statements on attentional focus during treadmill running in low- and high-anxiety condition

	Condition			
	Low anxiety		High anxiety	
	Number of statements	percentage	Number of statements	percentage
Movement execution	6	13.6%	9	17.7%
Worries and distracting thoughts	8	18.2%	22	43.1%
External - task relevant	15	34.1%	13	25.5%
External - task irrelevant	7	15.9%	2	3.9%
Positive monitoring	8	18.2%	5	9.8%
Total	44	100.0%	51	100.0%

Discussion

In the current study, the effects of state anxiety on running and combined running and dart throwing were investigated. First, perceived state anxiety was significantly higher when running on a treadmill high on a scaffold than when running on a treadmill near the ground. Second, as expected, participants seemed to focus their attention more on worries and distracting thoughts with than without anxiety. Third, there were several indications that efficiency was affected by anxiety as more mental effort was invested, oxygen uptake and heart rate were higher, and gait parameters changed. Fourth, just as in previous studies on anxiety and aiming, dart throwing was also affected by anxiety (e.g. Oudejans & Pijpers, 2009, 2010; Vickers & Williams, 2007; Wilson et al., 2009a, 2009b). Dart performance was significantly lower and performance times were higher with anxiety. Finally, dart throwing itself also affected oxygen uptake, heart rate, and running parameters, implying an accumulated effect of anxiety and dart throwing.

As for attention, in line with attentional control theory, anxiety seemed to distract attention away from task-related information towards task-irrelevant stimuli (i.e. worries; Eysenck & Calvo, 1992; Eysenck et al., 2007). Whereas in the low-anxiety condition participants' attentional focus was mostly directed at the dart board and the treadmill (task-related information), thoughts in the high-anxiety condition were more about preventing falling (threat-related worries). These changes in attentional focus provide a first indication that attentional control shifted from goal-directed to stimulus-driven during running with anxiety (Eysenck et al., 2007; cf. Oudejans et al., 2010). It seems that participants found it difficult to disengage from worrying about falling off the scaffold. Further research with more explicit measures of attention (e.g. gaze behavior) is needed to provide more insight into the mechanisms through which attentional control changes when running under stressful circumstances.

Anxiety and the accompanying changes in attention led to less efficient running, even though running, just as walking, is often considered to be highly automated. That mental effort was higher with anxiety suggests that processing efficiency was reduced, which is in line with attentional control theory (Eysenck et al., 2007). The higher oxygen uptake or higher energy expenditure with anxiety means that running is less efficient. Similar changes in running economy have also been found by Schücker et al. (2009) with different attentional focus instructions. Schücker et al. found that running was less efficient with an internal focus of attention than with an external focus of attention. This supports our idea that the changes we found in running economy were related to the changes in attention, from task-relevant external matters to threat-related internal worries.

The higher energetic costs with anxiety are likely the result of the changes in gait parameters. With anxiety stride frequency was significantly higher and contact times were longer, whereas stride length was shorter, resembling a more conservative gait pattern (Barak, Wagenaar, & Holt, 2006; Brown et al., 2006; Maki, 1997). In other studies, metabolic costs were found to be higher when participants ran with a gait pattern other than the preferred one (Cavanagh & Williams, 1982; Dallam, Wilber, Jadelis, Fletcher, & Romanov, 2005). Note that the instructed running speed in the current study was also the ‘‘preferred’’ one. Anxiety may have pushed runners out of their preferred mode into less efficient running. In this process, movements may have become more rigid (Beuter & Duda, 1985; Pijpers, Oudejans, Holsheimer, & Bakker, 2003), possibly contributing to the higher energetic costs of running. This fits with the ideas of Hatfield and Hillman (2001) and Janelle and Hatfield (2008), who addressed psychomotor efficiency and found that anxiety induces less efficient motor cortex activity, resulting in constrained and inhibited movement patterns. Despite the increases in heart rate and oxygen uptake, participants’ perceived physical exertion did not increase with anxiety. As self-report scales are not as sensitive as physiological measures, it is possible that the physiological changes observed in the current study may not have been large enough to elicit changes in Borg scale scores.

An additional increase in perceived mental effort and longer performance times in the high-anxiety condition suggest that performance on the dart throwing task was less efficient with anxiety. Despite the extra mental effort invested, dart performance deteriorated with anxiety. Similar results have been reported by Causer et al. (2011) for skeet shooting, Nieuwenhuys and Oudejans (2011) for handgun shooting, and Wilson et al. (2009a, 2009b) for basketball and penalty shooting, respectively. Causer et al. (2011), for example, showed that with anxiety, shooters had less efficient gun motion and higher mental effort scores as well as decreased shooting performance. Causer et al. suggested that the drop in performance was caused by a decrease in goal-directed attention as participants’ final fixation on the skeet became shorter with anxiety (cf. Nieuwenhuys & Oudejans, 2011; Wilson et al., 2009a, 2009b). In the current study, the available attentional resources might not have been sufficient to address attention towards worries, running, and dart throwing simultaneously, an interpretation that would again be in line with attentional control theory.

When running was combined with both anxiety and dart throwing, the effects of anxiety and dart throwing seemed to accumulate, showing the largest values on all kinematic and consequently metabolic variables in this combined condition (except of course for stride length where it elicited the lowest value). These findings are consistent with earlier findings by Williams and colleagues (Williams, Vickers, & Rodrigues, 2002), who reported accumulating effects of anxiety and task complexity (i.e. high and low attentional demands) on performance accuracy, reaction time, and invested mental effort in table tennis.

In conclusion, state anxiety not only affects perceptual-motor aiming tasks, but also tasks that rely heavily on the aerobic system, such as running. With anxiety, running kinematics became less efficient, resulting in higher energetic costs. Furthermore, when tasks that rely on the aerobic system and aiming tasks are combined an accumulated effect occurs, implying that running, aiming, and anxiety all compete for attention, leading to suboptimal attentional control and a decrease in performance. Further studies are needed to investigate whether these findings generalize to exercise with different intensities, different stressors, and different task combinations, especially because there are several fields in which high-intensity running is combined with aiming tasks, such as ball sports, but also police work, fire fighting, and military operations. An important question that remains is if and how the negative effects of anxiety in those tasks may be countered. Recent studies by Oudejans and colleagues on aiming tasks without running (dart throwing, basketball free throw shooting, and handgun shooting) show that training with elevated levels of anxiety holds promise in this regard (Nieuwenhuys & Oudejans, 2011; Oudejans, 2008; Oudejans & Pijpers, 2009, 2010). Whether training with anxiety is also effective in preventing negative effects of anxiety in tasks that rely heavily on the aerobic system needs to be established in future research.

3

Effects of anxiety, a cognitive secondary task, and expertise on gaze behavior and performance in a far aiming task

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Abstract

Previous studies focused on investigating the separate effects of anxiety, cognitive load, and expertise on perceptual-motor performance, but the combined effects of these factors have not been studied yet. The objective of the current study was to investigate these factors in combination. To that aim, eleven expert dart players and nine novices performed a dart throwing task in low-anxiety (LA) and high-anxiety (HA) conditions with and without a secondary task. The dart throwing task was performed low (LA) and high (HA) on a climbing wall and with and without the secondary counting backwards task. Performance and efficiency of task execution and gaze behavior were assessed. The anxiety manipulation evoked a decrease in dart performance, but only for the novices. Increases in mental effort and dart times and a decrease in response rate on the secondary task were observed for both groups. This shows that there were decreases in processing efficiency with anxiety. Most important, the anxiety-induced decrease in performance for the novices was accompanied by final fixations on the target that were substantially shorter and deviated off the target earlier. The dual task did not affect performance. Anxiety affects efficiency and sometimes performance in far aiming tasks. Changes are accompanied by changes in gaze behavior, particularly the final fixation on the target. All in all, findings provide support for Attentional Control Theory as a suitable framework to explain the effects of anxiety, a cognitive secondary task, and expertise in far aiming tasks.

Keywords: anxiety, attentional control theory, dart throwing, gaze behavior

Introduction

An increasing number of studies have investigated the negative effects of anxiety on performance in far aiming tasks. However, in high pressure contexts such as sports, policing, firefighting, and military operations people often combine aiming with cognitive tasks such as strategic decision making. The workload that is imposed by a secondary cognitive task has been found to evoke decreases in aiming performance in previous studies (e.g., Koedijker, Oudejans, & Beek, 2007, 2008; Mullen, Hardy, & Tattersall, 2005). Naturally, a third factor that mediates a person's performance in aiming tasks is their level of expertise. In the current study anxiety, a cognitive secondary task, and expertise were investigated in combination to further our understanding of how these factors influence far aiming.

A recent theory that describes the underlying mechanisms of the effects of anxiety on task execution is Attentional Control Theory (ACT, Eysenck et al., 2007). ACT was derived from Processing Efficiency Theory (PET, Eysenck & Calvo, 1992) and was originally developed to explain the effects of anxiety on cognitive performance. Eysenck et al. (2007) stated that anxiety can elicit a shift in attention from goal-directed to stimulus-driven, thereby increasing the distribution of attentional resources toward threat-related stimuli at the expense of attention allocated to the task. For example concerning aiming tasks, Wilson et al. (2009) showed that under elevated levels of anxiety football players focused relatively longer on the goalkeeper (a potential threat to task execution) and shorter on the goal-target area compared to low levels of anxiety. This decrease in visual attention toward the goal-target area appeared to be detrimental to shooting performance. In addition to environmental distracters, such as the goalkeeper, cognitive distracters, such as worrisome thoughts, are also expected to threaten task execution (e.g., Oudejans et al., 2011).Worries are thought to consume attentional resources, thereby reducing attentional capacity available for task execution (Eysenck & Calvo, 1992). As a result, task efficiency almost always decreases, sometimes also followed by a drop in performance.

Originally, most research on ACT was concerned with performance on cognitive tasks as these tasks often rely heavily on working memory. Meanwhile however, findings that support ACT are also provided for perceptual-motor tasks, particularly far aiming tasks (e.g., Nieuwenhuys & Oudejans, 2010; Wilson et al., 2009ab). In far aiming tasks it was found that performance decrements under anxiety were accompanied by changes in gaze behavior such as increases in the number of fixations (e.g., Wilson et al., 2009ab) and decreases in the duration of the final fixation on the target, also often referred to as the quiet eye period (e.g., in archery, Behan & Wilson, 2008; in basketball free throw shooting, Vine & Wilson, 2011; Wilson et al., 2009a; in golf putting, Vine, Moore, & Wilson, 2011; and in shooting, Causer et al., 2011; Nieuwenhuys & Oudejans, 2011; Vickers & Williams, 2007). Particularly the timing and duration of the final fixation on the target appear to be essential for performance (De Oliveira, Oudejans, & Beek, 2006; Vickers, 1996; Vickers, Rodriguez, & Edworthy, 2000). In other words, when and for how long performers look at the target prior to and during the final action is closely related to performance. Shorter or not optimally timed final fixations to the target provide a shorter period to detect task-relevant information necessary for successful performance (Vickers et al., 2000). As an example, Vickers et al. (2000) found that expert dart players’ final fixation deviated off the target earlier in misses compared to hits, implying that they no longer looked at bull’s eye just before they released the dart.

One would expect the effects of anxiety on task efficiency and performance to be even more pronounced in tasks that are attention demanding or that are combined with an attention demanding secondary task. Many studies in the cognitive domain support this contention (e.g., Eysenck et al., 2005). However, direct tests of this working memory prediction of ACT for precision tasks remain scarce. An exception is the study by Williams et al. (2002), who investigated the effects of anxiety in a table tennis task with low and high demands on working memory. They showed that decreases in task efficiency with anxiety were greater when the demands on working memory were higher. Also, Murray and Janelle (2003) combined a simulated driving task with a secondary visual search task and compared performance with and without anxiety. It appeared that performance on the secondary task (visual search task) decreased with anxiety, indicating that with anxiety insufficient attention was available to perform both tasks simultaneously.

Proceeding on ACT’s predictions on working memory capacity, one would also expect different effects of anxiety on expert and novice perceptual-motor performance. In general, skills get automated over practice, thereby reducing the attentional resources necessary to perform a certain task (e.g., Brown & Carr, 1989). In other words, novices are expected to allocate much attention to the planning, selection, and control processes concerning task execution, while this is no longer the case for experienced performers whose task execution is highly automatized. As such, novices are likely to be affected more by anxiety as the limit of their attentional resources will sooner be exceeded, due to the extra attention that is consumed by anxiety. As a result, less attention would be left available for task execution, resulting in a decrease in performance. However, studies that compare novice and experts performance with anxiety are scarce. An exception is a study by Williams and Elliott (1999), who investigated the effects of anxiety and expertise on visual search strategies in karate. Experts and novices moved in response to videotaped karate offensive sequences. Although both novices and experts performed better with anxiety, their gaze behavior was differentially affected (Williams & Elliott, 1999). With high-anxiety, novice karate performers fixated shorter on the locations on the opponent’s body that were related to attacking movements, whereas for experts’ the duration of the fixations on these locations increased. No studies comparing effects of anxiety and expertise in aiming tasks have been executed.

In short, until now the effects of anxiety, cognitive load, and expertise have only been tested in isolation, thereby providing only indirect evidence of the link between these variables. However, as mentioned, in police and sports practice far aiming tasks and cognitive tasks are often combined in stressful situations. Furthermore, for novices, performing these aiming and cognitive tasks is expected to demand more attention than for experts. The purpose of the current study was to combine anxiety, cognitive load, and expertise and investigate the effects of these factors on performance and visual attention in a dart throwing task. We compared dart throwing behavior of novice and competition darters with and without anxiety, and with and without a cognitive secondary task, namely, counting backwards. Counting backwards was chosen as a secondary task because dart players should be more familiar with this task as calculating the next goal-target (by subtracting scores) is part and parcel of playing darts. As such, we expected this task to be more automated for dart players and more attention demanding for novices. To manipulate anxiety, participants performed a dart task high and low on a climbing wall. This method was already applied successfully in previous studies (e.g., Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008; Oudejans & Pijpers, 2009, 2010).

Our first aim was to explore which of the three factors and which combinations of these factors would evoke a decrease in dart performance. Second, following ACT, we predicted that anxiety would negatively affect processing efficiency (Eysenck et al., 2007). Decreases in processing efficiency were expected to become manifest via increases in perceived mental effort, increases in dart times, decreases in response rate on the secondary task, and changes in gaze behavior. Specifically, due to anxiety, attention was expected to shift from goal-directed to more stimulus-driven. Decreases in goal-directed attention were expected to manifest themselves in shorter final fixations on the target as this leaves less time to detect stimulus information (Vickers et al., 2000). Increases in stimulus-driven attention were expected to result in increased distractibility as indicated by an increase in scan ratio (e.g., Wilson et al., 2009ab), and earlier offset of the final fixation on the target (e.g., Vickers et al., 2000; Wilson et al., 2009). Third, the shorter final fixations were expected to be accompanied by worse performance (e.g., Vine et al., 2011; Vine & Wilson, 2011). Fourth, as both anxiety and counting backwards were expected to consume attention, and thus evoke changes in processing efficiency and performance, we expected these changes to be the largest when dart throwing was combined with both anxiety and counting backwards (Eysenck et al., 2007). Finally, as novices were expected to need more attention for the dart task and the counting task than experts, decreases in efficiency and performance were predicted to be larger for novices (Eysenck et al., 2007).

Method

Participants

Eleven male, right-handed, experienced dart players (with a mean age of 34.2 years, *SD* = 9.6 and a mean experience of 11 years, *SD* = 5) and nine students without experience in dart throwing (with a mean age of 22.9 years, *SD* = 1.7, 4 women and 5 men), volunteered to take part in this study. All participants were informed about the procedure of the experiment and they all provided informed consent prior to the start of the experiment. The experiment protocol was reviewed and approved by the local ethics committee. All participants completed the Dutch version of the A-trait scale of the State-Trait Anxiety Inventory (STAI, Van der Ploeg et al., 1980). The mean trait scores for male dart players (mean = 32.4, *SD* = 8.3) and male students (mean = 29.2, *SD* = 6.5) did not differ significantly from the mean scores for Dutch male college students (mean = 36.1 for men, Van der Ploeg et al.), $t_{10} = 1.50$, $p = .165$ and $t_4 = 2.36$, $p = .076$, respectively. The mean trait scores for female students (mean = 37.3, *SD* = 2.8) did also not differ significantly from the mean scores for Dutch female college students (mean = 37.7 for women, Van der Ploeg et al.), $t_3 = 0.33$, $p = .765$. Furthermore, trait scores for female participants did not differ from trait scores for male participants, $t_{18} = 1.48$, $p = .157$. These results indicate that participants had no extraordinary tendency to respond to situations perceived as threatening with high levels of state anxiety and that female participants did not have a larger tendency to respond with high levels of state anxiety than male participants. All participants had normal vision and had no experience in climbing or other activities that included height.

Design

Each participant was measured individually and all measurements were carried out on the same day. Participants threw 4 times 6 darts positioned low on the wall to familiarize with dart throwing while standing on the wall and to minimize learning effects (Oudejans & Pijpers, 2010). Then, participants threw 4 times 6 darts in a low- (LA) and high-anxiety (HA) condition, in a counterbalanced design (cf. Oudejans & Pijpers, 2009, 2010). Within conditions, participants performed a single task (single) and a dual task (dual) in a counterbalanced design, resulting in a total of four condition-task combinations.

Materials and measures

To manipulate anxiety participants performed the dart throwing task while positioned on an indoor climbing wall (width = 3.5 m, height = 7.0 m, cf. Oudejans & Pijpers, 2009, see Figure 3.1). Foot rails (length = 0.13 m, width = 0.85 m) were attached to the climbing wall at 0.2 m and at 5.0 m above ground level. Handholds were attached at 1.7 m above the foot rails. A stepladder enabled participants to take position high on the climbing wall (see Figure 3.1). Height has been successfully applied as manipulation of anxiety in previous studies (e.g., Nibbeling, Daanen, Gerritsma, Hofland, & Oudejans, 2012).

Manipulation check

To check whether the anxiety manipulation was successful, we used an anxiety scale called the anxiety thermometer. The anxiety thermometer is a visual-analog scale and consists of a 10-cm continuous scale ranging from 0 (not anxious at all) to 10 (extremely anxious). It was validated by Houtman and Bakker (1989) and was successfully used in earlier experiments (e.g., Oudejans & Pijpers, 2009, 2010). Compared to the CSAI-2 the anxiety thermometer showed a very quick way to measure anxiety. The anxiety thermometer does not differentiate between cognitive and somatic anxiety. However, Bakker et al. (2003) showed that anxiety thermometer scores correlate equally with the cognitive and somatic anxiety scores on the CSAI- 2, with correlation coefficients of 0.52 and 0.62, respectively.

Heart rate was assessed as a physiological measure of anxiety as physical activity of dart throwing was expected to be similar across conditions (Frijda, 1986). During the experiment heart rate was registered every 5 s using a Sport tester (Polar Sports Tester telemetric).

Dart task

In the LA and HA condition a dart board (d = 0.46 m) was attached at official competition distances (2.37 m in front of the participants with bulls eye positioned at 1.73 m above the participants' feet). The dart board contained ten black and white circles varying in corresponding points. Bull's eye corresponded to 10 points. Further outward, points decreased with 1 point per circle. No points were assigned for darts that failed to hit the board. Six darts were placed in a cup that was attached to the climbing wall near the right handhold. Dart performance was defined as the average score per dart. Dart time was defined as the time in seconds from the point of receiving the six darts for one trial to the release of the sixth dart. Thus, dart times only included dart throwing. After each block of six darts scores were counted and darts were removed from the board and returned to the participant (these actions were not included in the dart times).

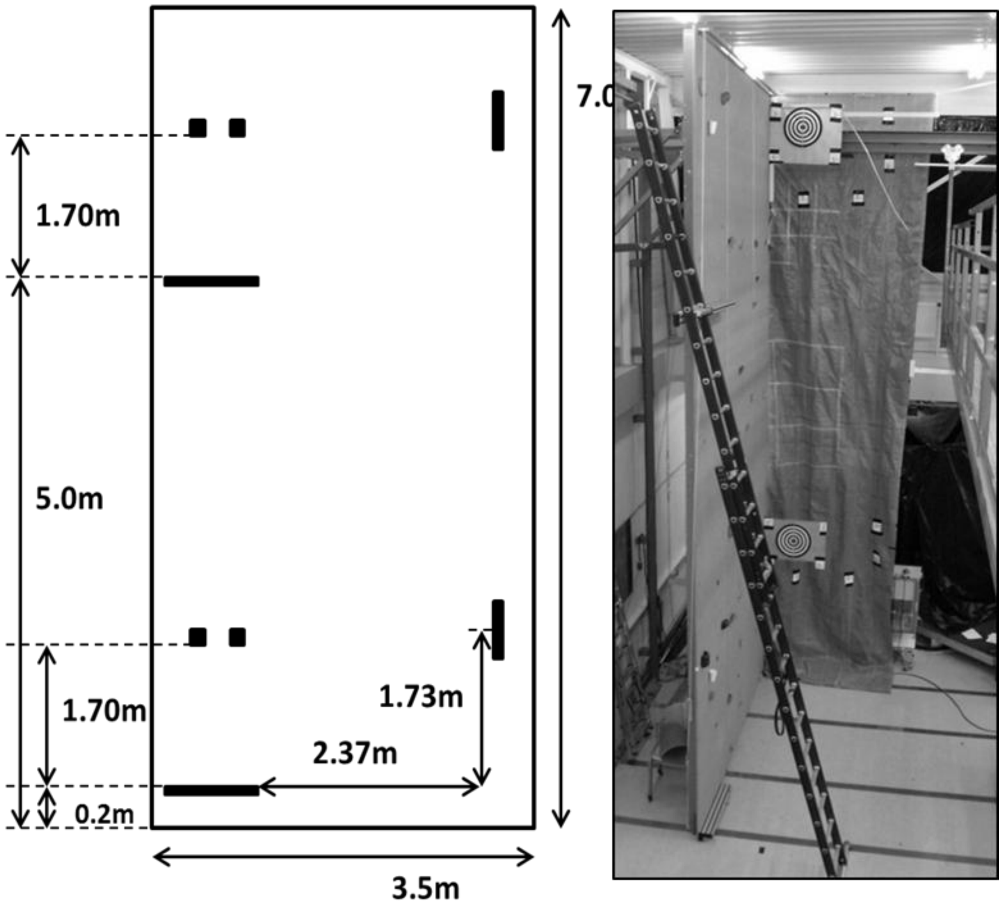

Figure 3.1. Front view (left) and side view (right) of the climbing wall and dart boards.

Secondary task

The secondary task consisted of counting backwards, a task with high cognitive demands which was successfully used in previous studies (e.g., Eysenck et al., 2005). Participants were instructed to count back from a random number between 500 and 1000 in steps of three. Performance on the secondary task was assessed by calculating the percentage of right answers. Efficiency was assessed by determining the response rate (number of answers per minute).

Mental and physical effort

Zijlstra's (1993) Rating Scale of Mental Effort (RSME) was used to assess the amount of mental effort participants perceived as most representative of the mental workload they had invested in the dart throwing task. Participants gave an indication of their mental effort invested on a vertical scale from 0 (absolutely no effort) to 150 mm (most effort ever). The RSME was proven valid and reliable by Veltman and Gaillard (1993) and was used successfully in earlier studies (e.g., Oudejans & Pijpers, 2009, 2010). Given that the task in the current study was not a pure cognitive task but a perceptual-motor task we also assessed participants' ratings of perceived exertion (RPE) as a measure of physical effort. For this we used the Dutch translation of the Borg Scale (Borg, 1982). The Borg Scale ranges from 0 to 10, with 0 reflecting total rest and 10 corresponding to maximal perceived physical exertion.

Gaze behavior

To assess gaze behavior the mobile eye tracker (Applied Science Laboratories, Bedford, USA) was used. The mobile eye consists of an eye camera and a scene camera (29.97 Hz) that are mounted on a pair of sports glasses. The mobile eye was used to assess participants' line of gaze on the basis of the images of both cameras combined. Furthermore, an external camera (digital camcorder, Canon ZR 850, 29.97 Hz) was positioned at 4.0m from the climbing wall so that gaze behavior could be related to participants' dart throwing movements.

Gaze measures were taken from the moment participants' gaze entered the dart board until dart release. The eyes had to be directed at one point for at least three successive frames (99.99 ms) to be considered a fixation (Vickers, 1996). Three fixation locations were distinguished; (a) bulls eye, (b) dart board, and (c) other (outside the dart board). For each throw the total fixation duration per location was calculated (ms), which was obtained by multiplying the number of fixations on each location by the duration of the fixation. While doing the analyses we also observed gaze behavior in which gaze drifted away from bulls eye (for at least three successive frames) before returning to the bull's eye again (cf. Leech, Gresty, Hess, & Rudge, 1977). Thus, these were neither fixations nor saccades but gaze drifts wandering away from and back to bull's eye, the amplitude of which varied from two to about seven scoring circles around bull's eye. We referred to such gaze behavior as a gaze drift and reported the total drift duration of these gaze drifts. Together, this resulted in four gaze locations: bull's eye, dart board, other, and drifts. Second, scan ratios were calculated as a measure of gaze stability. Scan ratio was defined as the number of fixations divided by the total duration of fixations across all locations. Third, the moments of final fixation onset and offset were introduced as measures of the timing of the final fixation. Therefore, the gaze data that was collected by the mobile eye tracker was synchronized with the participant’s movements (as recorded with the external camera) using Quiet Eye Solutions software (www.QuietEyeSolutions.com). Before the measurements started participants clapped their hands to provide a common point in both videos to synchronize the images. The dart movement consisted of participants taking a dart from the cup and fluently moving it upward into a stable position in front of their body and aiming toward the dart board. Then, a final arm movement was performed to throw the dart. Consequently, trial onset was defined as the first moment the dart aimed in a stable manner at the target and trial offset was defined as the moment of dart release (Vickers et al., 2000). Concerning the eye movements, final fixation onset was defined as the moment at which the final fixation on bulls eye was initiated relative to the moment of dart release (ms) and final fixation offset as the moment at which this final fixation deviated off bull’s eye relative to the moment of dart release (ms). Finally, the duration of the final fixation on the target was defined as the time between onset and offset (ms).

Procedure

Upon arrival, participants were informed about the procedure. They gave written informed consent and completed the STAI and the first anxiety thermometer to get familiar with the scales. Participants put on a heart rate monitor and their heart rate at baseline was determined. The eye-tracking device was fitted on the participants head and they took position low on the climbing wall. Then, participants threw 24 practice darts. They were instructed to score as many points as possible. After the practice trials, participants were fitted with a climbing harness and they took position high or low on the wall for the first experimental condition. The mobile eye was calibrated, and participants started with either the single or the dual task consisting of 4 x 6 throws. After each block of six throws scores were reported and the darts were removed from the board and returned to the participant on the wall. Between tasks, participants stayed positioned on the wall and the calibration of the mobile eye was repeated. Directly after finishing a task, participants completed the anxiety thermometer, RSME, and Borg scale. Then, they continued with the next task. After the first anxiety condition, participants came off the wall for a 10-min break. After the break, participants took position on the wall for the second anxiety condition (either high or low, depending on the first anxiety condition), the mobile eye was calibrated again and the condition started. In the dual task condition, participants started counting backwards before the first dart throw. Prior to the HA condition, participants climbed the ladder and rested on the platform to ensure that participants from both sequences started the trial in the same physical condition (non-fatigued).

Data analysis

Anxiety scores, heart rate, dart scores, dart times, RSME, RPE, scan ratios, and onset, offset, and duration of the final fixation were submitted to 2 x 2 x 2 (anxiety level [LA, HA] x task [Single, Dual] x expertise [dart player, student]) ANOVAs with repeated measures on the first two factors. Dual task response rates and the percentages of correct counts were analyzed using a 2 x 2 mixed design ANOVA (anxiety level [LA, HA] x expertise [dart player, student]). We performed a 2 x 2 x 2 (anxiety level [LA, HA] x task [Single, Dual] x expertise [dart player, student]) MANOVA with repeated measures on the first two factors on the following three[1] dependent variables, 1) total fixation duration on bulls eye, 2) total fixation duration on dart board, and 3) total drift duration. Following significant multivariate effects separate univariate ANOVAs were conducted. Effect sizes were calculated using Cohen's f with 0.10 or less, about 0.25, and 0.4 or more, representing small, moderate, and large effect sizes, respectively (Cohen, 1988). When sphericity was violated, Greenhouse Geisser corrections were applied. Gaze behavior was analyzed by two independent observers from video images. The intra-observer reliability was 97.8%. The inter-observer reliability was 93.9%. Linear regression analyses were performed on dart performance and final fixation durations to assess the degree to which the duration of final fixation predicted performance.

Results

Manipulation check

A complete overview of the means and *SD*s of the manipulation checks is provided in Table 3.1.

Anxiety scores

Anxiety scores showed significant main effects for anxiety level, $F_{1,\,18} = 36.23$, $p < .001$, Cohen's $f = 1.42$, task, $F_{1,\,18} = 8.35$, $p = .010$, $f = 0.69$, and expertise, $F_{1,\,18} = 6.75$, $p = .018$, $f = 0.61$, as well as a significant interaction between anxiety level and expertise, $F_{1,\,18} = 4.69$, $p = .044$, $f = 0.52$. Post-hoc pair-wise comparisons revealed that students had higher anxiety scores in the HA condition than dart players, $p = .016$, 95% CI [0.5, 4.6], while in the LA condition this difference just failed to reach significance, $p = .056$. Most important, both students and dart players reported higher anxiety scores in the HA compared to the LA condition, *p*s < .01, 95% CI [1.7, 3.8], indicating that the anxiety manipulation was successful for both groups. Furthermore, anxiety scores were higher during the dual task compared to the single task, indicating that the dual task also evoked anxiety.

Heart rate

Heart rate showed significant main effects for anxiety level, $F_{1,\,18} = 6.14$, $p = .024$, $f = 0.61$, task, $F_{1,\,18} = 8.98$, $p = .008$, $f = 0.73$, and expertise, $F_{1,\,18} = 7.86$, $p = .012$, $f = 0.69$. There were no significant interaction effects. Heart rates were significantly higher in the HA compared to the LA condition, 95% CI [0.6, 7.9], which supports the conclusion that the anxiety manipulation was successful. Heart rates were also significantly higher during the dual task than during the single task, 95% CI [1.0, 5.8]. Furthermore, heart rates were lower for students compared to dart players across conditions, 95% CI [3.9, 27.4]. This expertise difference is probably due to a difference in physical fitness between the students and the dart players. The students were very

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[1] As fixations to locations in the category 'Other' only occurred rarely, the number of missing values for this category was too large to include these data in further analysis.

fit and active sport students and three of them had rest heart rates of around 40 bpm, indicating an exceptional fitness level.

Table 3.1. Mean values for the manipulation checks (including SDs) during dart throwing in low- and high-anxiety conditions and during single and dual tasks

	Students				Dart players			
	Low Anxiety		High Anxiety		Low Anxiety		High Anxiety	
	Single task	Dual task	Single task	Dual task	Single task	Dual task	Single task	Dual task
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Manipulation check								
Anxiety scores (0 -10)	1.9 (1.2)	3.0 (2.3)	4.8 (2.9)	5.7 (3.0)	1.2 (1.0)	1.5 (0.9)	2.5 (1.5)	2.8 (1.5)
Heart rate (bpm)	94.8 (14.0)	99.0 (11.0)	101.6 (16.9)	106.3 (17.6)	114.2 (9.8)	116.4 (12.7)	115.5 (9.5)	118.0 (10.9)

Dart scores and dart times

A complete overview of the means and *SD*s for dart scores, dart times, performance on the secondary task, and invested effort is provided in Table 3.2.

Dart scores

The ANOVA revealed a significant main effect for expertise, $F_{1, 18} = 40.89$, $p < .001$, $f = 0.61$, while the main effect for anxiety level as well as the interaction between anxiety level and expertise approached statistical significance at the 0.05 level, $F_{1, 18} = 3.92$, $p = .063$, $f = 0.47$, and $F_{1, 18} = 3.52$, $p = .077$, $f = 0.45$ (both large effect sizes), respectively. As all three p-values were below .10 we decided to follow-up on the interaction effect.[2] The post-hoc pair-wise comparisons revealed that for students dart scores were lower in the HA condition compared to the LA condition, $p = .018$, 95% CI [0.1, 0.7], whereas for dart players dart scores did not differ between anxiety levels, $p = .940$. Furthermore, at both anxiety levels, dart players performed better than students, *p*s < .001, 95% CI [2.0, 4.0]. Dart scores did not differ between tasks, $F_{1, 18} = 0.54$, $p = .471$.

Dart times

Dart times showed a main effect for anxiety level, $F_{1, 18} = 5.70$, $p = .028$, $f = 0.56$, and task, $F_{1, 18} = 5.17$, $p = .035$, $f = 0.53$, as well as a significant interaction between task and expertise, $F_{1, 18}$

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[2] That the interaction only approached significance may be due to a lack of power. One way to increase the power that is actually suggested in the statistical literature is to increase alpha to 0.10 (Stevens, 1996), in which case the interaction would be significant. Therefore we decided to perform the post-hoc analyses, especially given the large effect size.

= 11.84, *p* = .003, *f* = 0.82. Dart times were significantly longer in the HA condition than in the LA condition, 95% CI [0.3, 5.1]. Furthermore, post-hoc pair-wise comparisons revealed that dart times of the dart players were longer in the single task compared to the dual task condition, *p* = .001, 95% CI [1.8, 5.9], while this was not the case for the students, *p* = .420. Furthermore, in the single task condition dart times of dart players were longer than those of the students, *p* = .012, 95% CI [1.4, 10.3]. However, dart times did not differ between dart players and students in the dual task condition, *p* = .630.

Dual task

Response rate

Response rate only showed a significant main effect for anxiety level, $F_{1,18}$ = 24.00, *p* < .001, *f* = 1.15. On average, participants gave less counts per minute in the HA than in the LA condition, 95% CI [1.2, 3.1] (see Table 3.2). Response rates did not differ between expertise levels, $F_{1,18}$ = 1.84, *p* = .192. There were no significant interaction effects.

Percentage of correct counts

The percentage of correct counts did not differ significantly between anxiety levels, $F_{1,18}$ = 0.20, *p* = .662, or expertise levels, $F_{1,18}$ = 1.18, *p* = .293. There were no significant interaction effects, *F*s < 0.61, *p*s > .447.

Invested effort

Invested mental effort

Scores for perceived mental effort showed significant main effects for anxiety level, $F_{1,18}$ = 13.61, *p* = .002, *f* = 0.87, and task, $F_{1,18}$ = 21.07, *p* < .001, *f* = 1.08, as well as a significant interaction between task and expertise, $F_{1,18}$ = 4.58, *p* = .046, *f* = 0.50. More mental effort was invested in the HA than in the LA condition, 95% CI [7.1, 25.7]. Furthermore, post-hoc pair-wise comparisons revealed that for students, the dual task led to higher mental effort scores, *p* < .001, 95% CI [12.7, 34.5]. However, for dart players this difference did not reach significance, *p* = .085. In both the single and the dual task condition mental effort scores did not differ between expertise levels, *p*s > .1. Thus, overall, mental effort was higher in the HA compared to the LA condition and students invested more mental effort in the dual task compared to the single task condition (see Table 3.2).

Perceived exertion

Participants' ratings of perceived exertion (RPE) only showed a significant main effect for anxiety level, $F_{1,18}$ = 9.05, *p* = .008, *f* = 0.72. Participants' RPE were significantly higher in the HA than the LA condition, 95% CI [0.3, 1.7], indicating that participants perceived the tasks as more physically exerting with anxiety. RPE did not differ between tasks, $F_{1,\,18} = 0.49$, $p = .492$, or expertise levels, $F_{1,\,18} = 1.60$, $p = .222$.

Gaze behavior

A complete overview of the means and *SD*s for the gaze parameters is provided in Table 3.3.

Scan ratio

Scan ratio showed a significant main effect for anxiety level, $F_{1,\,10}$[3] $= 6.70$, $p = .027$, $f = 0.82$, and task, $F_{1,\,10} = 28.23$, $p < .001$, $f = 1.69$. Both groups had higher scan ratios in the HA compared to the LA condition, 95% CI [0.1, 1.1], and in the dual task compared to the single task condition, 95% CI [0.2, 0.4]. Scan ratio did not differ between expertise levels, $F_{1,\,10} = 2.73$, $p = .130$. There were no significant interaction effects, *F*s < 1.72, *p*s > .219.

Total fixation duration and drift duration

The 2 x 2 x 2 MANOVA on the total fixation and drift durations only revealed a significant main effect for anxiety level, $F_{3,\,8} = 6.38$, $p = .016$, $f = 1.56$. Separate follow-up univariate ANOVAs revealed a significant main effect of anxiety level on the total duration of fixation on bulls eye, $F_{1,\,10} = 15.44$, $p = .003$, $f = 1.25$, and a marginally significant main effect of anxiety level on the total drift duration, $F_{1,\,10} = 4.90$, $p = .051$, $f = 0.70$ (a very large effect size). In sum, both groups fixated shorter on bulls eye, 95% CI [266, 962], and seemed to show longer drifts in the HA compared to the LA condition, 95% CI [-1, 358] (see Table 3.3).

Duration of the final fixation on bull's eye

The duration of the final fixation showed significant main effects for anxiety level, $F_{1,\,10} = 14.39$, $p = .004$, $f = 1.20$, and expertise, $F_{1,\,10} = 6.43$, $p = .030$, $f = 0.80$. Final fixations were significantly shorter in the HA compared to the LA condition and for students compared to dart players. The duration of the final fixation did not differ between tasks, $F_{1,\,10} = 1.95$, $p = .192$, and there were no significant interaction effects, *F*s < 0.49, *p*s > .499. To provide additional insight on the changes in the duration of the final fixation we obtained an indication of its timing by analyzing the onset and offset of the final fixation.

Final fixation onset

Final fixation onset showed a significant main effect for anxiety level, $F_{1,\,10} = 8.05$, $p = .018$, $f = 0.90$ while the main effect for expertise just failed to reach significance, $F_{1,\,10} = 4.47$, $p = .061$, $f = 0.67$ (a large effect size). Final fixation onset was on average 397 ms later in the HA than in the LA condition, 95% CI [85, 709], and on average 394 ms later for students than for dart

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[3] Gaze behavior data of seven participants (4 dart players and 3 students) failed.
Analysis of all other variables excluding these seven participants led to the same pattern of results as analysis with these seven included (thus with all participants).

players, 95% CI [-21, 809], (see Table 3.3). Final fixation onset did not differ between tasks, $F_{1, 10} = 0.19$, $p = .200$, and there were no significant interaction effects, *F*s < 0.49, *p*s > .498.

Final fixation offset

Final fixation offset showed a significant main effect for anxiety level, $F_{1, 10} = 21.44$, $p = .001$, $f = 1.46$, while the main effect for expertise, $F_{1, 10} = 3.44$, $p = .093$, $f = 0.59$ (a large effect size), as well as the interaction between anxiety level and expertise showed mild trends, $F_{1, 10} = 4.09$, $p = .071$, $f = 0.64$ (a large effect size). Post-hoc pair-wise comparisons revealed that for students, gaze deviated off the target earlier in the HA than the LA condition, $p = .001$, 95% CI [77, 216], whereas for experts there was only a mild trend, $p = .095$, 95% CI [-12, 127]. Furthermore, in the HA condition there was a trend toward gaze deviating off the target earlier for students than for experts, $p = .077$, 95% CI [-18, 295], while this was not the case in the LA condition, $p = .176$. Final fixation offset did not differ between tasks, $F_{1, 10} = 0.11$, $p = .743$.

Regression analysis

Linear regression analyses were performed solely on the two anxiety levels without the dual task since the dual task did not evoke changes in performance. For the dart players, linear regression analysis revealed that the average duration of the final fixation ($n = 6$) predicted 89% of the variance in performance during the HA condition, $R^2 = 0.887$, $\beta = 0.94$, $p = .005$. For the students, the average duration of the final fixation ($n = 7$) marginally significantly predicted 63% of the variance in performance during the HA condition, $\mathrm{R}^2 = 0.634$, $\beta = 0.80$, $p = .058$.

Table 3.2 Mean values for invested effort, dart scores, and dart times (including SDs) in low- and high-anxiety conditions and during single and dual tasks.

	Students				**Dart players**			
	Low Anxiety		High Anxiety		Low Anxiety		High Anxiety	
	Single task	Dual task	Single task	Dual task	Single task	Dual task	Single task	Dual task
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Dart task								
Dart score (per dart)	4.89 (1.62)	4.83 (1.26)	4.51 (1.88)	4.44 (1.56)	7.89 (0.80)	7.78 (0.60)	7.88 (0.53)	7.78 (0.85)
Dart time (s)	28.28 (4.58)	28.42 (3.79)	30.34 (5.52)	31.77 (8.06)	33.27 (6.60)	30.52 (5.80)	37.11 (5.67)	32.16 (7.17)
Dual task								
Nr of responses (min^{-1})		21.7 (6.8)		19.4 (6.1)		25.4 (6.5)		23.4 (6.1)
Correct answers (%)		96.5 (4.2)		97.3 (5.5)		98.7 (2.1)		98.4 (2.6)
Invested Effort								
Mental effort (0-150)	30.9 (18.9)	56.8 (25.6)	52.9 (42.6)	74.2 (39.6)	35.5 (23.4)	46.1 (21.8)	50.6 (20.8)	57.1 (26.9)
Perceived exertion (0-10)	2.4 (1.1)	2.5 (1.3)	3.5 (2.2)	4.0 (2.7)	3.5 (0.8)	3.2 (0.6)	3.9 (1.2)	4.2 (0.9)

Table 3.3 Mean values for the gaze parameters (including SDs) during dart throwing in low- and high-anxiety conditions and during single and dual task.

	Students				Dart players			
	Low Anxiety		High Anxiety		Low Anxiety		High Anxiety	
	Single task	Dual task	Single task	Dual task	Single task	Dual task	Single task	Dual task
	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)
Gaze data								
Scan ratio (sec^{-1})	1.24 (0.78)	1.45 (0.45)	1.77 (0.86)	2.22 (1.06)	0.84 (0.30)	1.01 (0.15)	1.21 (0.34)	1.64 (0.86)
Gaze locations								
Total fixation duration BE (ms)	1455.7 (864.3)	1474.6 (245.1)	783.4 (600.2)	717.9 (456.2)	2065.6 (634.3)	2065.9 (656.7)	1682.6 (400.2)	1421.3 (694.6)
Total fixation duration DB (ms)	218.6 (249.0)	369.8 (166.0)	207.4 (209.5)	393.0 (280.3)	250.4 (189.4)	273.8 (195.0)	660.6 (593.5)	545.8 (723.4)
Total fixation duration O (ms)	34.0 (83.3)	151.9 (121.1)	76.3 (101.5)	50.7 (74.5)	0.0 (0.0)	10.4 (16.2)	42.7 (67.9)	49.3 (85.4)
Total drift duration (ms)	214.9 (128.2)	201.7 (143.2)	325.7 (145.6)	298.2 (169.0)	308.2 (441.2)	240.0 (192.8)	611.7 (571.1)	442.2 (357.5)
Final Fixation on bulls eye								
Final Fixation Onset (relative to dart release, ms)	1345.9 (619.0)	1261.8 (229.4)	954.2 (508.4)	897.5 (343.1)	1832.0 (578.8)	1601.2 (422.3)	1403.6 (355.0)	1197.6 (433.9)
Final Fixation Offset (relative to dart release, ms)	78.5 (55.6)	84.7 (114.6)	350.7 (428.5)	269.9 (257.7)	29.2 (25.6)	35.4 (39.9)	113.5 (93.5)	65.9 (46.8)
Duration Final fixation (ms)	1267.4 (658.2)	1177.1 (309.5)	684.3 (490.4)	627.6 (406.1)	1802.8 (594.4)	1565.7 (428.2)	1355.0 (371.3)	1149.0 (431.9)

Note. BE = on bulls eye, DB = on dart board, O = on areas other than dart board

Discussion

The aim of this study was to investigate the combined effects of anxiety, cognitive load, and expertise on performance and gaze behavior in an aiming task (dart throwing). Similar to previous studies, the manipulation of anxiety using height was successful (e.g., Oudejans & Pijpers, 2009, 2010). Furthermore, anxiety evoked a mild, yet significant decrease in dart throwing performance, but only for the students. Anxiety also had a negative effect on processing efficiency, as indicated by the longer dart times, lower response rates on the secondary task, increases in invested mental and physical effort, and changes in gaze behavior with anxiety. Finally, the dual task resulted in a greater investment of mental effort for the students, but not for the dart players. For the sake of clarity, the findings for the different groups will be discussed separately in what follows, starting with the students.

For students, the negative effects of anxiety were more pronounced than for the dart players. In line with ACT, anxiety negatively affected students' processing efficiency as well as their dart performance, indicating that for students not enough attentional resources were left available to maintain performance with anxiety. As students also had higher anxiety scores high on the wall than dart players we cannot be sure whether these more pronounced negative effects were the result of students' higher perceived anxiety or of expertise differences (less automated task execution). However, in either case, students' decrease in performance was accompanied by shorter final fixations on the target with anxiety. This is consistent with previous studies where a reduction in the duration of the final fixation on the target led to decreases in aiming accuracy (e.g., in archery by Behan & Wilson, 2008; in handgun shooting by Nieuwenhuys & Oudejans, 2011; in basketball by Wilson et al., 2009a). A shorter final fixation is an indication of a reduction in goal-directed attention, implying less time for detecting stimulus information and linking relevant stimuli to appropriate motor responses (Corbetta, Patel, & Shulman, 2008; Corbetta & Shulman, 2002). As students' final fixations halved with anxiety (from approximately 1200 ms - 650 ms, see Table 3.3), the remaining duration of the final fixation was apparently not sufficient to maintain performance. This is further supported by the regression analyses, which showed that shorter final fixations predicted decreased performance with anxiety, although the results of the regression analyses should be interpreted with caution given the low sample sizes. Students' performance only showed a mild decrease with anxiety (around 8%). However this decrease is comparable to previous studies on skeet shooting (11.7%, Causer et al., 2011) and penalty kicks (around 11.9%, Wilson et al., 2009a). Furthermore, in actual darts the difference between winning and losing may be the result of a dart landing only millimeters from the target. With anxiety students' scores were around half a point lower. This corresponds with half a circle (11 mm) further away from the target which is large enough to be decisive in actual darts.

Furthermore, the trends in the results regarding the timing of the final fixation provided additional information on the gaze changes that occurred with anxiety. Students' final fixations were initiated later, closer to dart release, with anxiety and deviated off the target earlier. Low on the wall students' final fixations were initiated 1300 ms before dart release, whereas high on the wall gaze this was approximately 920 ms before dart release. Furthermore, while low on the wall final fixations deviated off target close to dart release, this occurred about 300 ms before dart release high on the wall. De Oliveira et al. (2006) and Vickers et al. (2000) showed that pick-up of visual information as late as possible, that is, as close to ball or dart release as possible, is crucial for good performance in far aiming. Thus, the changes in final fixation offset might therefore further explain students' decrease in performance with anxiety. Besides the changes in final fixation, scan ratios were higher and gaze drifts were longer high on the wall, indicating that the students were distracted more easily with anxiety (e.g., Wilson et al., 2009ab). In line with ACT, these changes with anxiety suggest a shift from goal-directed attention to stimulus-driven attention.

Not only were the effects of anxiety more pronounced for the students than for the dart players, as expected, the dual task was more effortful for the students as well. In line with our hypotheses, this implies an accumulated effect of anxiety and the secondary counting backwards task as both anxiety and counting backwards evoked an increase in invested mental effort. These results support earlier findings by Nibbeling et al. (2012) and Williams et al. (2002) who found accumulating effects of anxiety and attentional load on invested effort in a running and table tennis task, respectively. For students (compared to dart players), combined dart throwing and counting backwards did not seem to be automated (e.g., Brown & Carr, 1989). As expected, students invested more mental effort in the dual task (dart throwing and counting) than in the single task (dart throwing). However, despite this increase in mental effort, performance did not decrease in the dual task. Visual inspection of the data revealed that this might be due to the nature of the secondary task (counting backwards) which allowed participants to time the counts in between the dart throws. Alternating between the tasks reduced the cognitive load of the dual task, which might explain why students maintained performance in the dual task condition. Scan ratios were also higher in the dual than the single task. A possible explanation might be that gaze wandered off between throws when participants tried to recall the next number in the counting backwards task, leading to more fixations.

As predicted, dart players showed less pronounced effects of anxiety and the dual task than the students. Dart players performed better than the students and although their processing efficiency decreased, they managed to maintain performance high on the wall while students did not. The findings on gaze behavior provide an explanation for this maintained performance. Consistent with previous studies on novice-expert differences in rifle shooting (Causer, Bennett, Holmes, Janelle, & Williams, 2010; Janelle et al., 2000) and free throw shooting in basketball (Wilson et al., 2009a), dart players' final fixations were longer than those of the students (almost twice as long, see Table 3.3). Therefore, although dart players' final fixations duration also became shorter with anxiety just as for the students, they were clearly still long enough to ensure good performance. With anxiety, dart players' final fixations were even still a little bit longer than that of the students in the low-anxiety condition (about 1250 vs 1200 ms). Again, as high on the wall the dart players were less anxious than the students we cannot be sure whether these results were due to the students' higher perceived anxiety or to expertise differences.

Still, Vine and Wilson (2010) found similar results for trained and untrained golf putters. Although final fixations became shorter with anxiety in both groups, this was only accompanied by a decrease in performance for the untrained group. In line with Vine and Wilson, we suggest that reductions in final fixation duration only lead to decreased performance when this duration drops below a critical threshold. Concerning timing, final fixations of the dart players deviated off the target approximately at dart release in both anxiety conditions (about 30 ms before dart release in the low-anxiety conditions and about 90 ms in the high-anxiety condition). Contrary to the students, who's gaze deviated off the target about 300 ms before dart release in the high-anxiety condition (see Table 3.3), the dart players thereby meet the suggestion by De Oliveira et al. (2006) and Vickers et al. (2000) that picking-up information as late as possible is essential for good performance. Furthermore, just as anxiety, the dual task also did not affect performance for the dart players. Dart players invested some extra mental effort when dart throwing was combined with counting backwards, however, not significantly more. As hypothesized, this indicates that dart players perceived dart throwing combined with counting backwards as less effortful than the students.

As mentioned, in practice, aiming tasks are often combined with cognitive tasks. In high pressure contexts, such as policing, firefighting, and military operations, but also in tactical ball games such as basketball and handball, people combine aiming with strategic decision making. For novices, these combinations of tasks appear more effortful and performance appears more susceptible to anxiety. Furthermore, gaze appears to play an essential role in anxiety-induced performance decrements. Recent studies showed that gaze training can increase attentional control and performance under pressure (Vine et al., 2011; Vine &Wilson, 2010, 2011; Wood & Wilson, 2011). These studies primarily focused on the duration of the final fixation on the target. Whereas timing of the final fixation was included in the gaze training instructions, the changes or improvements in timing were not reported. However, from recent studies (including the current study) the suggestion rises that timing of the final fixation is also crucial for performance (De Oliveira et al., 2006; Vickers et al., 2000; cf. Oudejans, van de Langeberg, & Hutter, 2002). We therefore recommend future research to include changes in timing of the final fixation and to investigate its trainability in gaze training programs.

In sum, this study was the first to investigate the combined effects of anxiety, a cognitive secondary task, and expertise on aiming performance. It appeared that anxiety negatively affected processing efficiency in both groups. Furthermore, with anxiety performance on the dart task decreased, but only for the students. It is not surprising that only students' performance was negatively affected as gaze indices showed that for novices final fixations on the target halved and thereby probably decreased below a critical threshold needed to maintain performance. Students' final fixation deviating off target well before dart release might also have contributed to the performance decrement. Together, the changes in gaze behavior suggest that goal-directed attention decreased while stimulus-driven attention increased. For the students, performing the dart task and the secondary task simultaneously was also more effortful than just dart throwing, whereas for experts it was not. In general, the findings provide support for Attentional Control Theory (ACT) as a suitable framework to explain the effects of anxiety, a cognitive secondary task, and expertise in far aiming tasks.

4

Pursue or shoot? Effects of exercise-induced fatigue on the transition from running to rifle shooting in a pursuit task

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Nicky Nibbeling, Raôul R.D. Oudejans, Rouwen Cañal-Bruland, Peter van der Wurff, & Hein A.M. Daanen (2013). Pursue or shoot? Effects of exercise-induced fatigue on the transition from running to rifle shooting in a pursuit task. *Ergonomics, 56,* 1877-1888. DOI: 10.1080/00140139.2013.847213

Abstract

To investigate to what degree exercise-induced fatigue influences behavioral choices, participants' transition from running to rifle shooting in a pursue-and-shoot task was assessed. Participants ran on a treadmill and chased a target in a virtual environment and were free to choose when to stop the treadmill and shoot at the target. Fatigue increased progressively throughout the 20-minute test. Results indicated that shooting accuracy was not affected by fatigue. However, the distance to the target at which participants decided to shoot showed a U-shaped relationship with fatigue, $R^2 = 0.884$, $p = 0.013$. At low fatigue levels (ratings of perceived exertion [RPE] < 6.5), the distance to the target at which participants shot decreased, whereas at higher fatigue levels (RPE > 6.5) shooting distance increased again. At high levels of fatigue, participants stopped running sooner, aimed at the target longer and shot less often. Findings indicate that physiological parameters influence not only perception but also actual transitions between different actions.

Keywords: action possibilities, behavioral choices, exercise-induced fatigue, far aiming, virtual environment

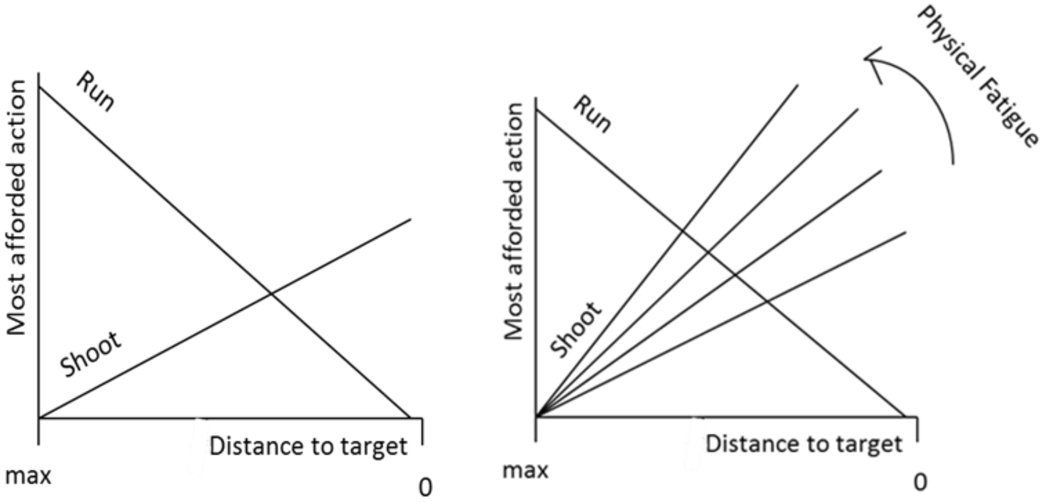
Introduction

In many high-achievement settings action possibilities rapidly appear and vanish. People constantly have to consider which actions to execute. For example, in ball sports, athletes may have a split second to decide whether to pass or shoot the ball before opponents' and teammates' positions have changed again. Police officers and soldiers also engage in dynamic situations in which decisions about when to shoot and where to aim are crucial, for instance, when pursuing a fleeing suspect. On the one hand, dynamic situations thus offer a variety of action possibilities such as running and shooting. On the other hand, this variety of action possibilities necessarily demands decisions about which action to execute and which not to execute. One factor that may influence such decisions is exercise-induced fatigue. Exercise-induced fatigue typically increases progressively throughout a sports match or pursuit. As a result, for example, a police officer who is fatigued and in pursuit of a suspect might not approach the target as closely as when he is not fatigued. Hence, when the police officer decides to shoot, he might shoot from too far away to get a clear shot, thereby increasing the risk of missing the target and consequently increasing the risk of unintended casualties. The current study provides a first step in investigating to what degree increasing exercise-induced fatigue influences such behavioral choices. To this end, we assessed shooting behavior in a pursue and rifle shoot task.

Previous research indicates that rifle shooting accuracy can be negatively affected by moderate or heavy exercise (e.g., Ito et al., 1999; Tharion et al., 1997; Vickers & Williams, 2007). Ito et al. (1999), for example, investigated the effects of intense aerobic exercise on rifle shooting accuracy. Participants ran on a treadmill or walked with a heavy backpack. Immediately thereafter, they positioned themselves at a set distance of 175 or 300 m from a pop-up target that they were instructed to shoot as soon as it appeared. Results demonstrated that shooting accuracy decreased after treadmill running as well as after walking with a heavy backpack. Similarly, Tharion et al. (1997) found that shooting accuracy reduced after participants completed a 15-km road march. Although a variety of studies focused on rifle shooting and exercise-induced fatigue, these studies solely assessed effects on shooting accuracy (e.g., Evans et al., 2003; Groslambert et al., 1999; Ito et al., 1999; Lakie, 2010; Tharion et al., 1997; Vickers & Williams, 2007). Notably, participants were always instructed to shoot from a set distance to the target. Hence, they did not take into account when people actually decide to shoot. However, in practice, the shooting distance is rarely set. The majority of practice situations are dynamic, as in the case of the police officer who pursues a suspect and has to decide on the right moment to stop running to shoot.

Such dynamic situations provide individuals with various possibilities for action. These possibilities for action are determined by the individual's intentions (for theoretical frameworks, see Gibson [1979] 1986; Proffitt & Linkenauger, 2013). For example, to shoot a target implies that an officer perceives pursuing and shooting as the two appropriate actions. Subsequently, the officer needs to decide when to run and when to shoot. Whether an individual perceives running or shooting as a possible action is susceptible to the influence of external factors. One factor that might influence this decision is exercise-induced fatigue. Previous studies indicate that peoples' perceived action possibilities decrease when they are subjected to moderate or intense exercise (Bhalla & Proffitt, 1999; Pijpers, Oudejans, & Bakker, 2007; Proffitt et al., 1995). Pijpers et al. (2007), for example, instructed people to climb to exertion on a climbing wall and asked them to judge their maximum reaching distance at low and high levels of perceived exertion. Higher perceived exertion was associated with decreases in perceived maximum reaching distance. Similarly, inducing fatigue by having people complete an exhausting run resulted in people perceiving a hill to be steeper than when people were rested (Bhalla & Proffitt, 1999; Proffitt et al., 1995). Also, participants who wore a heavy backpack judged the hill to be steeper than their counterparts without a backpack.

Thus, to date, we know that exercise-induced fatigue can negatively affect shooting accuracy. Furthermore, there is evidence that exercise-induced fatigue influences how people perceive action possibilities. However, no studies focused on whether exercise-induced fatigue also leads to changes in choices for certain actions. Therefore, to gain insight into the degree to which exercise-induced fatigue influences the actual transition from one action to another, we designed a pursue and rifle shoot task and manipulated exercise-induced fatigue through running for an extended period. The pursue and rifle shoot task was chosen as it typically requires a transition from one action, pursuing, to another, shooting. In Figure 4.1a, this transition (distance to the target at which the actor stops running to shoot) is depicted for a random person. At very large distances to the target (Figure 4.1a, total left) participants were expected to start running to catch up with the target, whereas at very small distances to the target (Figure 4.1a, total right) participants were expected to shoot immediately. The transition from running to shooting is indicated by the point at which the two lines intersect. Clearly, the distance to the target at which this transition initially occurs depends on the actor's action capabilities. The initial transition may occur at different points within two extremes: on the one hand, a good runner might decide to run until he catches up with the target and then shoot; on the other hand, a good shooter might decide not to run at all and shoot immediately. Obviously, there are many possible choices for action in between these two extremes, and these choices may depend on exercise-induced fatigue. As this study is a first attempt to investigate these types of choices, it is quite exploratory in nature and does not necessarily allow to derive clear-cut hypotheses. Subsequently, we decided to gradually assess changes in the transition from running to shooting due to exercise-induced fatigue (see Figure 4.1b). In this model it is assumed that when in pursuit of a target, people constantly have to make a cost–benefit analysis. Approaching the target closer facilitates the rifle shooting task, but people then have to run longer, thereby increasing the physical costs. We expected peoples' running possibilities to decrease with increasing exercise-induced fatigue. In Figure 4.1b, we illustrate that at high levels of fatigue people were expected to stop running earlier and shoot from an increasingly greater distance to the target.



a. b.

Figure 4.1. (a) The transition from running to shooting (shooting distance) is indicated by the point where the lines cross. (b) Shift of the transition from running to shooting with increasing fatigue. The transition occurs at an increasingly greater distance to the target.

Thus, in the current study we aimed to take a first step towards a better understanding of the effects of exercise-induced fatigue on the decision about when to run and when to shoot in a pursue test. We investigated the degree to which exercise-induced fatigue influences people's actual transition from running to shooting (i.e. a kind of transition that is important in many high-achievement settings). Investigating the transition from running to shooting increases our understanding of these kinds of transitions and how they can be optimized. We proposed that the transition from running to stopping to shoot would shift in favor of the rifle shooting task with increasing fatigue, resulting in larger shooting distances at higher levels of fatigue (see Figure 4.1b). Furthermore, we expected that the increasingly larger shooting distances caused by increasing fatigue would result in a decrease in rifle shooting accuracy (e.g., Ito et al., 1999; Tharion et al., 1997). To this end, in the current study, people actually had to pursue a visually projected target with a gun in their hands in a virtual environment while exercise-induced fatigue progressively increased. Virtual environments are applied increasingly in academic disciplines because of their high adaptability to different test and training situations (Moskaliuk, Bertram, & Cress, 2013). Participants were instructed to hit as many targets as possible within 20 minutes. This implies that they had to decide while running when they were close enough to the target to shoot and hit the target. Subsequently, they stopped running, aimed and shot at the target. When the target was hit, a new target appeared. The goal was to hit as many targets as possible within
20 minutes.

Method

Participants

Seventeen students, 11 men (23.2 years, standard deviation [SD] = 2.2) and 6 women (26.2 years, *SD* = 8.4), participated in the experiment. The experiment was approved by the local ethics committee. Prior to the start of the experiment participants were informed about the procedure and provided written informed consent. All participants were college students, participating in different sports. None of the participants reported physical limitations during the time of measurement. Moreover, none of the participants had rifle shooting experience. A running test to exhaustion (mean duration 11.9 minutes, *SD* = 1.1) was performed prior to the pursue and shoot test. The test indicated that participants had a maximal rate of oxygen uptake (VO_2 max) of 48.3 ml/min/kg (*SD* = 6.9), a maximum heart rate of 199 bpm (*SD* = 7) and a maximum running velocity of 14.0 km/h (*SD* = 2.0).

Design

All participants completed two different tests, separated by 2–10 days. The first test was the treadmill running test to exhaustion, of which the data were used to define the personal retreat velocity of the target that would be pursued during the second test. The second test was the actual ‘pursue and shoot’ test. The pursue and shoot test consisted of eight blocks of 2.5 minutes of running and shooting such that fatigue would progressively increase from block to block. The test was developed in such a way that at baseline participants were able to shoot a target within 20–30 seconds, which means that five to eight shots could be fired per block of 2.5 minutes.

Materials and measures

Running test to exhaustion

The running test to exhaustion was performed on a treadmill (EN-BO systems model sport-reha, Amsterdam, the Netherlands). Respiratory gases and heart rate were analyzed using the K4 system (Cosmed, Rome, Italy). Maximal running velocities (Vmax) of participants were estimated on the basis of overall fitness level, running experience, gender and, if available, prior information from maximal running tests on a treadmill. The speed of the treadmill was increased every minute with x km/h, where x equals (Vmax - 7)/10. This protocol was used successfully in previous studies (e.g., Midgley, McNaughton, & Carroll, 2007). Exhaustion time was 13 minutes on average. Throughout the test, the inclination of the treadmill was set to 1% as this most accurately reflects outdoor running (Jones & Doust, 1996).

The CAREN system

The pursue and shoot test took place in a Computer Assisted Rehabilitation Environment (CAREN, Motek Medical BV, Amsterdam, the Netherlands) (see Figure 4.2a). The CAREN consists of a treadmill embedded in a movable platform, a surrounding virtual environment (curved screen 3 x 2 (width x height) meters) and an eight-camera Vicon (Oxford Metrics Inc., UK) camera set-up. Participants were prevented from falling by wearing a safety harness that was attached to a metal frame that was mounted on the treadmill platform. With the CAREN control software D-Flow 3.7.40 Beta, a virtual reality environment was created. The virtual environment contained a road with trees on the sides on which a round target was projected (2D) that moved away from the participant (see Figure 4.2b). The initial target distance was set at 62.5 m as test shooting indicated that participants always shot from within this distance. The CAREN has shown a suitable research tool to investigate human movement in a virtual reality environment in previous studies (e.g., Barton et al., 2006; Fung et al., 2006; McAndrew, Dingwell, & Wilken, 2010).

The treadmill was set to self-paced, which was controlled by two reflective markers that were attached to the participants' hips (left and right). The markers were detected by the Vicon cameras. The velocity of the treadmill increased by moving forward on the treadmill. By moving backward on the treadmill, the band slowed down and eventually stopped, allowing to take a shot. The maximum speed of the treadmill was 18 km/h.

Figure 4.2. (a) Photo of the CAREN system with the treadmill (embedded in the platform) and the projection screen. (b) Virtual environment including the round shaped target.

Manipulation check

We expected an increase in participants' fatigue level to be accompanied by increased ratings of perceived exertion (RPE) and heart rate. The RPE was assessed with the Borg scale (Borg, 1982). The Borg scale ranges from 0 to 10, with 0 reflecting no exertion at all and 10 corresponding to maximal exertion, and was found successful in measuring RPE in previous studies (Blacker et al., 2013; Nibbeling et al., 2012; Pijpers et al., 2007). Every 2.5 minutes (thus 8 times in 20 minutes), participants were asked to indicate how physically exerted they perceived themselves to be. Heart rate was assessed using a heart rate monitor (Suunto t6d Black Smoke Running Pack, Finland). During the test, heart rate was measured continuously.

The amount of mental effort participants invested in the pursue and shoot task was assessed every 5 minutes using the Rating Scale of perceived Mental Effort (RSME; Zijlstra, 1993). This vertical scale ranges from 0 (absolutely no effort) to 150mm (most effort ever). The RSME was proven valid and reliable by Veltman and Gaillard (1993) and has been used successfully in previous studies (e.g., Eaves, Hodges, & Williams, 2008; Nieuwenhuys & Oudejans, 2011; Oudejans & Pijpers, 2009, 2010).

Pursue and shoot measures

Whenever a participant pulled the trigger the D-Flow software registered the virtual shooting distance (in meters) between the participant and the target. Thus, virtual shooting distance was registered for every shot regardless of whether the target was hit or missed.

As a measure of shooting accuracy, the D-Flow software registered the number of hits. Since the number of shots taken could differ between participants, we calculated the percentage of hits as a second measure of shooting accuracy.

Assuming that participants would shoot from farther away when fatigued, participants might stop running earlier and consequently shoot from a greater distance to the target. Alternatively, participants could stop the treadmill at the same distance to the target but invest more time in aiming, which would also result in an increase in virtual shooting distance. Therefore, the distance between the participant and the target at which participants came to a full stop (the stopping distance) and the time participants invested in shooting (shooting times) were also assessed (see Figure 4.3).

To this end, complementary to the data from trigger pull, video footage was obtained. A camera (Vado HD digital camera) was situated 4 m from the treadmill at a nearly perpendicular angle. Due to technical difficulties these data were only obtained for seven participants. The moment at which participants came to a full stop on the treadmill and the moment of trigger pull were visible in the video recordings and were used to calculate shooting time (see Figure 4.3). Subsequently, to calculate stopping distance, shooting time was multiplied by the personal retreat velocity of the target (m/s) that was determined in the running test to exhaustion. The outcome of this multiplication was then subtracted from the shooting distance (m), resulting in the stopping distance in meters.

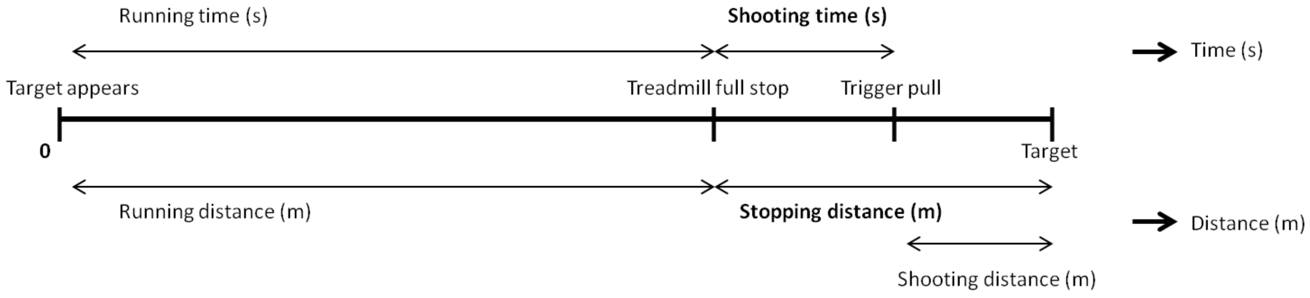


Figure 4.3. Overview of the distance and time variables.

Finally, average running speed (km/h) per block of 2.5 minutes was determined to assess whether participants reduced their running speed to compensate for the increase in fatigue. To this end, running distance (see Figure 4.3, registered by the D-Flow software) was divided by running time (obtained from the video footage). As the treadmill was set to self-paced, running speed changed continuously throughout the test. Consequently, slowing down to stop and shoot and accelerating again were included in the running speed.

Debriefing questionnaire

After participants finished the pursue and shoot test, they were asked how they had experienced the experiment in a debriefing questionnaire. The questionnaire was designed to gain insight into the different possible strategies participants had applied to gain as many points as possible.

Procedure

On the first test day participants performed the running test to exhaustion. On arrival, participants were informed about the procedure and gave their written informed consent. Then, participants put on the K4 and took position on the treadmill and the test started. After the test, the speed corresponding to 80% of participants' VO_2 max was registered which was set as participants' target speed for the pursue and shoot test. This target speed was on average 10.7 km/h (*SD* = 1.4). To ensure enough data points, 5 km/h was subtracted from this reference velocity and the resulting speed was set as the fixed retreat velocity of the target in the pursue and shoot test. The initial distance to the target in the pursue and shoot test was set at 62.5 m. Thus, to approach the target at their reference velocity, participants had to run (at least) 5 km/h faster than the target retreated. In practice, this resulted in participants catching up with the target every 30 – 45 seconds.

The pursue and shoot test took place at least 2 days and not more than 10 days after the maximal running test. Participants put on a heart rate monitor, took position on the treadmill and were fitted with a safety harness that was attached to the frame that was mounted to the treadmill. Before the actual test started, participants performed a warm-up that consisted of three parts. First, to familiarize participants with the shooting task, participants were instructed to shoot at a non-moving target that was projected at five different distances. At each distance, participants were allowed to take five shots. In the second part of the warm-up, participants practiced with accelerating and decelerating the treadmill. The participants had to walk or run for several seconds at 5 km/h, and at 60%, 70% and 80% of their maximal running velocities as attained during the maximal running test. Visual feedback about their current running speed was projected on the screen. In the third part of the warm-up, participants practiced with alternating between self-paced running and shooting as in the actual test, although they practiced on walking velocity to ensure participants would not get fatigued. To familiarize with the Borg and RSME scales, these were also assessed during the final part of the warm-up (after the 5th and 10th shot).

Just before starting the pursue and shoot test, participants were instructed to hit as many targets as possible and that one point was awarded for each target that was hit. Participants were allowed to take one shot each time they had stopped the treadmill and were to shoot only when standing still. When the target was hit, the next target appeared at its initial distance (62.5 m). If the target was missed, participants had to pursue the same target again. To motivate participants to perform at their best, the participant with the highest score was awarded a gift voucher of 50 Euros.

During the actual pursue and shoot test, participants ran on a self-paced treadmill for 20 minutes. The treadmill had the same inclination of 1% to match the maximal running test situation. The target was moving away from the participant at the fixed velocities as assessed during the maximal running test. After each block of 2.5 minutes, participants' perceived exertion was verbally obtained by asking the participants to call out how physically exerted they perceived themselves rated on a scale of 1 –10. Every 5 minutes, in a similar way, participants verbally rated their perceived level of mental effort. After the test was finished, participants sat down on a chair and completed the debriefing questionnaire.

Data analysis

Mean and *SD* values were calculated for all variables (for the sake of clarity standard errors of the mean [SEM] rather than *SD* values are presented in Figures 4.4 – 4.7). The assumption of normality was checked using the Shapiro–Wilks tests and by calculating the skewness and kurtosis of the frequency distribution. There were no violations of normality. Greenhouse–Geisser corrections were used to control for violations of homogeneity of variance. Borg scale scores (RPE) and heart rate were analyzed using one-way repeated measures analyses of variance (ANOVA) in which block (Blocks 1– 8) was the within-participant factor. The RSME were also analyzed using one-way repeated measures ANOVA with four blocks (i.e. after every second block). Exploration of the data clearly demonstrated that participants were still familiarizing with the pursue and shoot task in the first block which had not been practiced in full during the warm-up. It seemed that participants were still exploring the ideal shooting distance, something they also indicated in the debriefing questionnaire. Apparently, the warm-up period was not sufficient to get fully acquainted with the task. As the large differences between Block 1 and the other blocks distracted from the effects of fatigue in Blocks 2 –8 and as leaving Block 1 out of the analyses did not lead to any changes in the pattern of results of Blocks 2– 8, Block 1 was not included in the data analyses of the pursue and shoot variables. Thus, to analyze shooting distance (n = 17), shooting accuracy (n = 17), running speed (n = 7), stopping distance (n = 7) and shooting time (n = 7), one-way repeated measures ANOVAs were performed on Blocks 2 – 8. Results with p-values of ≤ 0.05 were considered statistically significant. Effect sizes were calculated using Cohen's f, with 0.10 or less, about 0.25 and 0.4 or more representing small, moderate and large effect sizes, respectively (Cohen, 1988). Significant differences were followed up using post hoc pair-wise comparisons using Bonferroni corrections for multiple comparisons when necessary (http://www.quantitativeskills.com/sisa/calculations/bonhlp.htm).

Results

Manipulation check

Table 4.1 gives an overview of the main results of the pursue and shoot test.

RPE and heart rates (*n* = 17)

The 20-min pursue and shoot test led to a progressive increase in fatigue. There was a significant effect of block for RPE, $F(1.7, 27.6) = 120.90$, $p < 0.001$, $f = 2.71$, and heart rate, $F(1.6, 21.0) = 127.68$, $p < 0.001$, $f = 3.18$. As can be seen in Table 4.1, participants' RPE gradually increased throughout the test and the value in each block was higher than that in the previous block, $p < 0.05$. Heart rates increased rapidly from the start of the test and stabilized after approximately Block 5. Heart rate in each block was higher than that in the previous block, $p < 0.05$, except for Blocks 6 and 7. At the end of the test, the heart rate reached values close to participants' maximal heart rates that were obtained during the running test to exhaustion. Both RPE and heart rate indicate that participants fatigued progressively throughout the test and that high levels of exercise-induced fatigue were reached.

Ratings of mental effort (*n* = 17)

There was a significant effect of block for participants' ratings of mental effort (RSME), $F(1.9, 30.4) = 37.55$, $p < 0.001$, $f = 1.53$. RSME scores increased progressively over the blocks and the value in each block was higher than that in the previous block, $p < 0.05$.

Table 4.1. Mean (SD) results for fatigue and shooting performance

Block	RPE‡ 0 - 10	HR◆ (bpm)	RSME‡ 0 - 150	Nr Shots	Nr Hits	% of hits
1	2.9 (1.4)	146 (15)		9.0 (2.7)	6.4 (2.6)	71 (13)
2	3.9 (1.4)	173 (14)	43 (20)	7.7 (2.4)	6.1 (2.3)	77 (17)
3	5.1 (1.7)	181 (12)		7.8 (2.5)	6.1 (2.6)	79 (24)
4	6.4 (1.7)	185 (11)	63 (28)	7.1° (2.4)	5.7 (2.3)	82 (19)
5	7.1 (1.9)	187 (11)		7.1° (2.0)	5.8 (2.1)	81 (14)
6	7.8 (1.8)	188 (12)	82 (32)	6.7†° (2.2)	5.2 (2.0)	76 (21)
7	8.4 (2.0)	189 (12)		6.9†° (2.5)	5.7 (2.6)	80 (16)
8	8.6 (2.0)	190 (13)	98 (39)	7.2 (2.1)	5.8 (2.5)	79 (17)

Note. Block 1 was excluded from analyses. RPE = Ratings of Perceived Exertion, HR = heart rate, RSME = Ratings Scale of Mental Effort.

‡ Values in all Blocks significantly higher than in all previous Blocks, $p < 0.05$.

◆Values in all Blocks significantly higher than in all previous Blocks, $p < 0.05$. No differences between Block 6 & 7, and Block 5 & 6.

† Significantly less than in Block 2, $p < 0.05$

°Significantly less than in Block 3, $p < 0.05$

Pursue and shoot measures

Shooting distance ($n = 17$)

There was a significant effect of block on the shooting distance, $F(2.3, 36.0) = 5.07$, $p < 0.001$, $f = 0.56$. Shooting distance showed a quadratic, U-shaped, relationship with increasing levels of fatigue, $R^2 = 0.884$, $p = 0.013$. Post hoc pair-wise comparisons revealed that shooting distance decreased until approximately Block 4 and then gradually increased again until Block 8, $p < 0.05$, $t > 2.10$ (see Figure 4.4). Moreover, shooting distance did not exceed the initial target distance of 62.5 m for any of the participants.

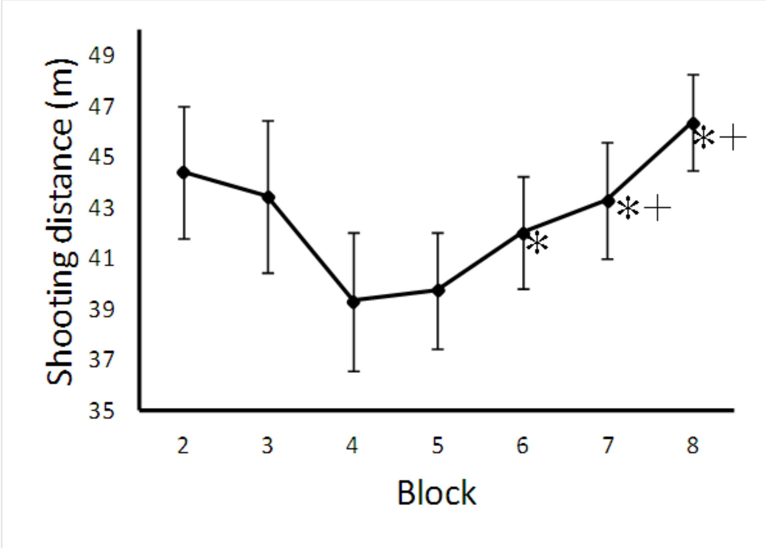


Figure 4.4. Distance to the target (n = 17) at which participants pulled the trigger per Block of 2.5 minutes. Values are means +/- SEM.
+ Significantly greater than Block 4, p < 0.05.
** Significantly greater than Block 5, p < 0.05.*

Shooting accuracy (n = 17)

There was a significant effect of block on the number of shots, F(6, 96) = 3.60, *p* = 0.003, *f* = 0.47. Post-hoc comparisons indicated that the number of shots was lower in Blocks 5 and 6 than in Block 2, and in Blocks 4 – 7 than in Block 3, *p* < 0.05, *t* > 2.13 (see Table 4.1).

Furthermore, the ANOVAs showed no significant effect of block on the number of hits, *F*(6, 96) = 1.41, *p* = 0.220, *f* = 0.29, or on the percentage of hits, *F*(6, 96) = 0.23, *p* = 0.966, *f* = 0.08. Thus, the changes in shooting distance across the blocks were not accompanied by changes in shooting accuracy (see Table 4.1). However, additional changes in pursue and shoot measures were obtained from the video footage as described below.

Running speed (*n* = 7)

The data from the video footage revealed that running speed did not change significantly during the test, *F*(2.5, 14.8) = 1.06, *p* = 0.384, *f* = 0.42, even though participants gradually became more physically fatigued (see Figure 4.5).

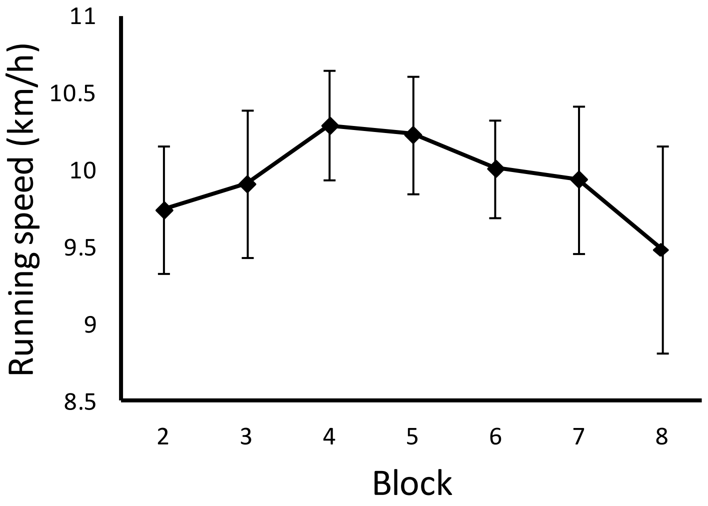


Figure 4.5. Participants' running speed per Block of 2.5 minutes (n = 7). Values are means +/- SEM.

Stopping distance ($n = 7$)

There was a significant effect of block on the stopping distance, $F(6, 36) = 2.34$, $p = 0.052$, $f = 0.62$. In line with the findings on shooting distance, stopping distance showed a trend towards a quadratic, U-shaped, relationship with block, $R^2 = 0.711$, $p = 0.084$. Post-hoc pair-wise comparisons revealed that stopping distance decreased from Block 2 to Block 4 and then gradually increased again to Block 8, $p < 0.05$, $t > 2.48$ (see Figure 4.6).

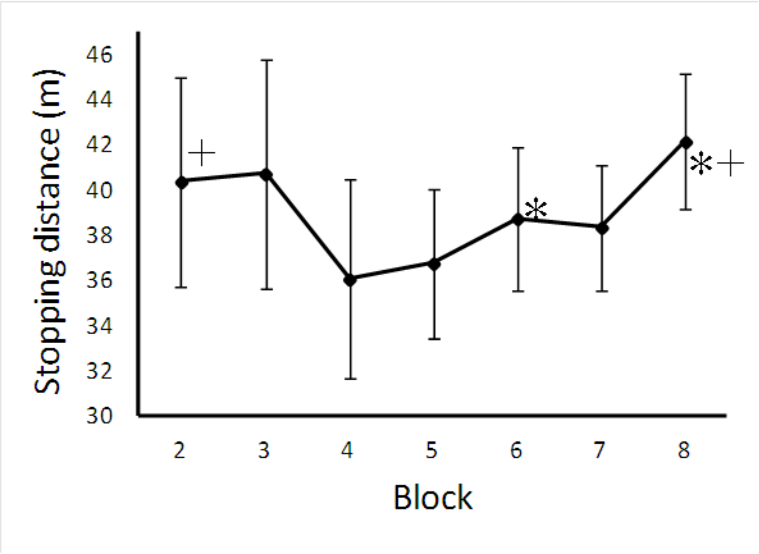


Figure 4.6. Distance to the target at which participants came to a full stop on the treadmill per Block of 2.5 minutes (n = 7). Values are means +/- SEM.
+ Significantly greater than Block 4, p < 0.05.
** Significantly greater than Block 5, p < 0.05.*

Shooting time ($n = 7$)

Finally, shooting time changed significantly throughout the test, $F(6, 36) = 5.87$, $p < 0.001$, $f = 0.98$. Post-hoc pair-wise comparisons revealed that shooting times were larger in the final two blocks than in the earlier blocks, $p < 0.05$, $t > 2.83$ (see Figure 4.7). Shooting time showed a possible linear ($R^2 = 0.97$, $p < 0.001$) or quadratic ($R^2 = 0.95$, $p < 0.001$) relationship with block. Most importantly, as participants became more physically fatigued they took more time to take a shot once they had stopped running.

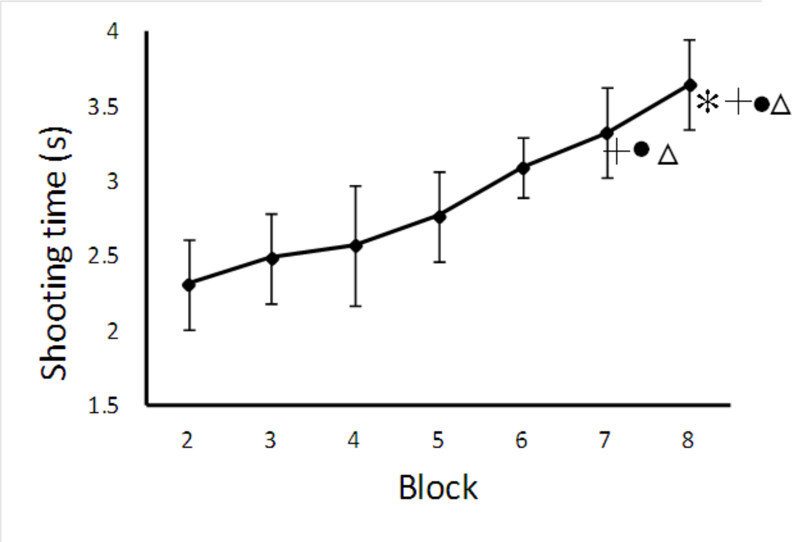


Figure 4.7. Shooting time per Block of 2.5 minutes. Shooting time (n = 7) was the average time that participants took to take the shot once they came to a full stop. Values are means +/- SEM.
** Significantly greater than Block 2, p < 0.05.*
• Significantly greater than Block 3, p < 0.05.
+ Significantly greater than Block 4, p < 0.05.
** Significantly greater than Block 5, p < 0.05.*

Discussion

This study aimed to explore the effects of increasing exercise-induced fatigue on the transition from running to shooting in a pursue and rifle shoot task. To that aim, participants ran on a treadmill and pursued a target in a virtual environment. Participants had to decide when they were close enough to the target to shoot and hit the target, and subsequently they stopped running, aimed and shot at the target. First, our results indicate that the manipulation of progressively increasing exercise-induced fatigue was successful. While running on the treadmill, participants' RPE and heart rate progressively increased over the 20-minute test (i.e. over the eight blocks). Most importantly, results indicated a U-shaped relationship between shooting distance and progressively increasing levels of exercise-induced fatigue. At low levels of fatigue (RPE < 6.5) the distance to the target at which participants shot decreased, whereas at higher levels of fatigue (RPE > 6.5) shooting distance increased again. At high levels of fatigue, participants decided to stop running at a further distance to the target. Thus, they decided to switch from running to shooting earlier. Furthermore, with increasing fatigue, participants took more time aiming at the gradually more distant target and shot less often. Shooting accuracy, which was assessed through the number of hits and percentage of hits, was not affected by increasing exercise-induced fatigue. Thus, with increasing fatigue the outcome (performance) of the pursue and shoot test did not change, but the way to reach the outcome did.

These findings support the notion that increasing exercise-induced fatigue not only influences perceptual estimates and judgments but also affects actual behaviors and transitions between different actions. In line with our hypothesis, at high levels of fatigue (RPE > 6.5), participants decided to stop running earlier and shoot from a greater distance to the target (see Figure 4.1b). It seems that participants evaluated the trade-off between effort-related costs and the accuracy-related benefits and selected their actions as to minimise physical effort. Whereas the cost –benefit approach provides an explanation for the upward part of the U-shaped curve, in the downward and lowest part of the curve, participants' actions could be explained best by the 'precautionary principle'. The 'precautionary principle' states that people tend to be 'better safe than sorry' (Dekay, Patin˜o-Echeverri, & Fischbeck, 2009). Following this principle, participants initially ran closer to the target to ensure a 'safe' (i.e. successful) shooting distance, that is a shooting distance that guarantees a high probability of a successful shot. Safety margins play an important role in many aspects of human action, for example, when passing through apertures, in crossing a street, when lifting weights and when driving a car (Horrey & Simons, 2007; Oudejans et al., 1996; Seo, 2009; Warren & Whang, 1987). Warren and Whang (1987) for instance demonstrated that people favoured safety margins when they passed through apertures of different widths. People already rotated their shoulders at door widths that were still wide enough to fit through, thereby allowing a safety margin for body sway and errors. Furthermore, the answers on the debriefing questionnaire support the notion that our participants built in a safety margin as they indicated that in the first part of the test their emphasis was mainly on being close enough to the target to hit it.

Contrary to our hypotheses, the increase in shooting distance with higher levels of fatigue (RPE > 6.5) was not accompanied by a decrease in shooting accuracy. Consequently, the data on stopping distance and aiming time provide insight into the result that shooting accuracy did not decrease with fatigue. The analyses revealed that there were two reasons for shooting distance to increase with higher levels of fatigue. First, participants stopped the treadmill at a greater distance to the target. Thus, in line with our expectations, participants' running capabilities seemed to decrease with increasing physical costs. Second, participants took more time in aiming at the target, which contributed to an increased shooting distance as the target kept moving away from the participants while they stood still. The additional aiming time might have compensated for any adverse effects of fatigue on shooting accuracy. Previous studies confirm that when more time is taken to aim at the target, higher shot accuracies can be obtained (e.g. Carillo et al., 2011; Goonetilleke, Hoffmann, & Lau, 2009; Nieuwenhuys & Oudejans 2011). Furthermore, on the debriefing questionnaire several participants added the remark that they took more time to shoot when they became more fatigued in order to rest a little bit. As resting increases the stability of aiming, this may have further prevented shooting accuracy from deteriorating (Goonetilleke et al., 2009; Lakie, 2010). Still, some caution is warranted in adopting these explanations, as in the current study we only had a rough indication of shooting accuracy (hit or miss). Consequently, we have to conclude that subtle changes in shooting accuracy might have been overlooked. For future studies, we therefore suggest the inclusion of a more precise accuracy measure in order to be able to substantiate the presented explanations.

In addition, one could argue that participants never permitted the shooting distance to become large enough to allow a decrease in shooting accuracy. Participants were free to choose the shooting distance, and it seems that the shooting distance at which shooting accuracy would significantly drop was never reached. A comparison of the shooting data from the practice round and that from the pursue and shoot test supported this contention. The initial distance at which a target appeared was 62.5 m. In the practice rounds, participants' shooting accuracy started to decrease from approximately 50 m or farther from the target. During the pursue and shoot test, participants shot from approximately 39 m to a maximum distance of 47 m from the target (see Figure 4.4). Thus, in the pursue and shoot test, participants did not approach the boundaries of their action capabilities but stayed within the range that was proven 'safe' (i.e. successful) in the practice rounds. These results suggest that participants not only applied a 'better safe than sorry' strategy during the first half of the test but that they chose a safe shooting distance throughout the test, even with high levels of fatigue. Participants thus invested more physical effort than necessary, especially in the first half of the task.

It should be noted that, as in the current study participants were novice shooters, the results do not necessarily apply to shooters of higher levels of expertise. Hence, we cannot draw conclusions on how police officers, soldiers or athletes will be influenced in their behavioral choices when they get physically fatigued. Yet, this study provides evidence that with increasing exercise-induced fatigue the behavioral choices that people make change and that these changes already occur in novice shooters. It is therefore plausible that exercise-induced fatigue also affects such behavioral decisions in expert shooters. However, whether or not these changes actually occur in experts should be further investigated. Experts might be more aware of the boundaries of their action capabilities and they may therefore approach these boundaries closer than novices. On the other hand, as described previously, people build in safety margins in many everyday tasks like passing through apertures and crossing a street (Horrey & Simons, 2007; Oudejans et al., 1996; Seo, 2009; Warren & Whang, 1987). These tasks are practised so frequently that most individuals could be considered experts in them. This would suggest that experts also tend to build in safety margins.

Moreover, in order to decrease unnecessary losses of energy we suggest future research to examine whether it is possible to decrease the encountered safety margins. Many high-achievement settings comprise transitions from running to shooting, such as policing and ball sports. In these settings, fatigue typically increases to severe levels throughout a pursuit or match, and the smallest amount of spare energy can be decisive to the outcome of an event. Training might provide a possible way to reduce these margins. Participants could, for example, receive feedback on the difference between their current shooting distance and the distance at which their performance decreased in the pre-test.

In conclusion, the current findings provide a first indication that people make different behavioral choices at different levels of exercise-induced fatigue. In the pursue and rifle shoot task, this led to a gradual change in the transition between running and shooting with increasing exercise-induced fatigue. When the physical costs become high, participants decide to stop running sooner and aim at the target longer, resulting in an increase in shooting distance. Moreover, the current results showed that an increase in shooting distance does not automatically dictate a decrease in aiming performance as participants can compensate for negative influences on shooting accuracy by aiming longer and avoiding the boundaries of their action capabilities by building in safety margins. We suggest future research to investigate to what extent these safety margins are also present in more competent rifle shooters and how they can be adjusted in order to accomplish maximal shooting accuracy with minimal energy expenditure.

5

The effects of anxiety and exercise-induced fatigue on shooting accuracy and cognitive performance in infantry soldiers

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Nicky Nibbeling, Raôul R.D. Oudejans, Emiel M. Ubink, & Hein A.M. Daanen (2014). The effects of anxiety and exercise-induced fatigue on shooting accuracy and cognitive performance in infantry soldiers. Accepted in *Ergonomics*.

Abstract

Operational performance in military settings involves physical and mental skills that are generally investigated separately in lab settings, leading to reduced ecological validity. Therefore, we investigated the effects of anxiety and exercise-induced fatigue, separately and in combination, on cognitive and shooting performance of 22 soldiers in a real world setting. Findings indicate that soldier's shooting accuracy and decision making and mathematical skills decreased significantly under anxiety. Whether exercise-induced fatigue was beneficial or detrimental to task performance depended on the task at hand. The increased arousal levels through exercise prevented shooting accuracy from deteriorating in the decision task. In contrast, cognitive performance suffered from the increased arousal: participants more often failed to shoot when being fired at by an opponent and also math performance seemed to decrease. We conclude that anxiety can deteriorate soldier performance and that exercise-induced fatigue may improve or deteriorate performance in combination with anxiety depending on the nature of the task.

Keywords: anxiety, cognitive performance, exercise-induced fatigue, shooting accuracy, soldiers

Introduction

In military environments, soldiers encounter a multitude of stressors. Soldiers have to deal with exercise-induced fatigue as they have to march over heavy terrain, lift equipment, and carry backpacks. At the same time, they are under the constant threat of an upcoming hostile attack leading to high levels of anxiety. Still, in the midst of a battle while fatigued and anxious, soldiers have to be able to distinguish between friendlies and enemies while remaining tactically focused and while maintaining their perceptual-motor skills, such as shooting their firearms (Ward et al., 2008; Wilson, Salas, Priest, & Andrews, 2007). Thus, even under fatiguing and dangerous circumstances soldiers are required to maintain both cognitive and perceptual-motor performance. Despite the clear presence of anxiety and exercise-induced fatigue in military environments, to date there is not much scientific research on the effects of these stressors on operational performance of soldiers. Research on the effects of cognitive fatigue on performance is extensive (e.g., Hancock & Szalma, 2008). However, there has been little consideration for fatigue induced through exercise, effects on soldier's shooting performance, or combined effects of different stressors (e.g., Eccles et al, 2011). Therefore, in the current study, we investigated the separate and combined effects of anxiety and exercise-induced fatigue on soldiers' cognitive and shooting performance in a realistic military practice setting.

Concerning anxiety, negative effects on cognitive and aiming skills are often suggested to be due to changes in attention (for theoretical frameworks see Eysenck, Derakshan, Santos & Calvo, 2007, Hancock & Warm, 1989, Nieuwenhuys & Oudejans, 2012). Anxiety is suggested to evoke a shift in attention from information that is relevant for execution of the task (task-relevant) towards information that is irrelevant for execution of the task (task-irrelevant). For example, if the threat of an upcoming hostile attack causes a soldier to pay attention to worries about the situation and its consequences (task-irrelevant) it is possible that crucial information from the environment (task-relevant) is not picked-up. As a result, performance on the task at hand is likely to suffer: the soldier might misinform team mates, decide on the wrong course of action, or trip over or collide with hazards. There is extensive empirical support for this line of thought concerning the effects of anxiety on basic cognitive skills (e.g., Beilock, Kulp, Holt, & Carr, 2004; Darke, 1988; Humphreys & Revelle, 1984). Basic cognitive skills, such as memory and math skills, are indispensable for soldiers in many tasks (e.g., communicating coordinates, remembering key features of the (hostile) environment, etc.).

Besides these basic skills, cognitive skills that typically apply to military performance include accurate decision making (e.g., distinguish between hostile and friendly) and vigilance (e.g., Dubik, 2003; Wilson et al., 2007). Accurate shooting decisions are considered crucial to performance in several high-achievement settings and have previously been investigated in policing. Nieuwenhuys, Savelsbergh, and Oudejans (2012) confronted police officers with an opponent in a video lab setting. The opponent either surrendered or aimed a gun at them, in which case they were instructed to return fire. Results indicated that police officers are more inclined to shoot surrendering suspects when confronted with a so called shoot-back canon that, when hit, inflicted a painful sensation. The threat of being hit led to higher levels of anxiety. Moreover, additional findings in the domain of policing and the domain of sports indicate that changes in attention through anxiety can also induce decrements in perceptual-motor performance (e.g., Nieuwenhuys & Oudejans, 2010; Oudejans, 2008; Wilson, Wood, & Vine, 2009). The studies by Oudejans (2008) and Nieuwenhuys and Oudejans (2010) found that police officers shoot less accurate when they are anxious. In these studies, anxiety was increased by confronting participants with an opponent that shot back at them with (painful) colored soap cartridges. Again, the threat of being hit led to higher levels of anxiety. Just as athletes and police officers, soldiers are considered to be able to deal with anxiety caused by threatening situations and armed opponents. However, knowledge is seldomly exchanged between the domains of sports, policing, and military, and to date, there has been little consideration for the effects of emotions such as anxiety on operational behavior of soldiers (Eccles et al., 2011).

A second factor that influences cognitive and perceptual-motor performance is exercise-induced fatigue. Fatigue is a complex concept that has many facets. There are different sources of fatigue, such as a lack of sleep, boredom, and physical exercise, that demand a different theoretical approach (Matthews, Desmond, Neubauer, & Hancock, 2012). In the domain of movement sciences, the effects on performance of fatigue that are induced through exercise are traditionally explained by arousal theories, such as the Yerkes and Dodson hypothesis (1908) and Kahneman’s (1973) multidimensional allocation of resources theory. According to arousal theories physical exercise is accompanied by an increase in arousal. Yerkes and Dodson suggest the relationship between physiological arousal and performance to have the shape of an inverted-U. Thus, with increasing physiological arousal performance increases towards an optimal performance point at moderate levels of arousal. As arousal continues to increase performance deteriorates. Kahneman (1973) proposed that besides by increased arousal, performance is also determined by the amount of mental effort that people invest in the task. At low and moderate arousal levels extra invested effort can compensate for performance losses. However, performance is proposed to decrease at very high arousal levels when the (limited) capacity for effort is exceeded. Moreover, according to arousal theories different tasks are suggested to respond differently to one particular level of arousal (Hockey & Hamilton, 1983). Consequently, each task has its specific inverted-U curve and very attention demanding tasks might suffer from an increase in arousal at an earlier stage than less demanding tasks. The investigation of the effects of one stressor on multiple tasks has been termed a broad-band approach (Hockey & Hamilton, 1983).

In the current study, tasks were performed after an acute boot of exercise to resemble soldiers’ working environment, that is characterized by periods of low-level physical activity (walking) interspersed with short periods of high-intensity activities (e.g., running). As a result of this particular scenario, soldiers will be moderately aroused during subsequent task performance (e.g., communicate coordinates or respond to hostile fire). Following Hockey and Hamilton (1983) we might then expect a decrease in performance for other cognitive tasks with heavy attentional demands such as math and memory. Moreover, for a less attention demanding task such as shooting, performance might decrease at a later stage and moderate arousal might result in maintained or even increased performance (Nibbeling, Oudejans, Cañal-Bruland, van der Wurff, & Daanen, 2013).

Regarding shooting accuracy, there are indications of an inverted-U shaped relation between exercise-induced fatigue and accuracy in biathlon shooting. Vickers and Williams (2007) assessed that biathlon athletes shot more accurate after exercising at 55% of maximum oxygen uptake than during the non-exercise pretest. Subsequent higher levels of oxygen uptake (up to 100%) were again accompanied by declines in shooting accuracy. In a military context, previous studies thoroughly investigated the effects of fatigue through sleep deprivation (e.g., Haslam, 2007; Rognum, Vartdal, Rodahl, Opstad, Knudsen-Baas, Kindt, & Withey, 1986). However, although simultaneous occurrence of threat and physical exertion closely resembles the demands that confront a soldier, research into the effects of exercise-induced fatigue on military performance remains scarce, just as research into the combined effects of anxiety and exercise-induced fatigue.

Therefore, in the current study we investigated the separate and combined effects of anxiety and exercise-induced fatigue on soldiers' cognitive and perceptual-motor performance. To allow appropriate generalization of conclusions to the military performance environment, we performed the measurements in a setting that approached military practice more closely than previous studies on soldier performance (e.g., Mahoney, Hirsch, Hasselquist, Lesher, & Lieberman, 2007; Lieberman et al., 2006). Studies on the nature and severity of performance decrements on the battlefield are practically non-existent due to the high risk of injury (or death) and the presence of actual casualties on the battlefield (Lieberman et al., 2005). Although the full range and intensity of combat cannot be simulated in an experimental setting, previous studies make clear that it is important to collect data during realistic exercises that more closely resemble actual task execution (Dicks, Button, & Davids, 2010; Mann, Williams, Ward, & Janelle, 2007; Mastroianni, Zupan, Chupa, Berger, & Wile, 2003). In laboratory settings it is often difficult to evoke the exact same behavior as in the field. Furthermore, measurements in more natural experimental settings do not yield the same results as measurements in laboratory settings (Dicks et al., 2010; Mann et al., 2007).

Therefore, we had Dutch infantry soldiers perform a realistic field track in a military training village. The field track included shooting and cognitive tasks and was performed under low and high anxiety, and with or without a preceding heavily fatiguing running exercise to induce moderate fatigue in the field track that followed. The shooting tasks comprised accuracy tests, and the cognitive tasks comprised a decision making task (shoot or don't shoot), solving mathematical problems, a memory task, and a vigilance task.

Thus, where previous studies either investigated effects of anxiety or exercise-induced fatigue on performance, the current study sought to combine these manipulations and examine their effects on soldier performance. Moreover, we aimed to examine to what extent effects previously found in lab studies are generalizable to ecologically more representative settings. In general, in line with lab studies, we expected reduced shooting and cognitive performance under anxiety. Just as in police officers, we expected soldier's shooting accuracy to be impaired under anxiety and to result in more false decisions regarding whether an appearing opponent was friendly or hostile (e.g., Nieuwenhuys & Oudejans, 2010; Oudejans, 2008; Wilson, Wood, & Vine, 2009). Moreover, more errors were expected in soldier's math and memory performance (e.g., Beilock et al., 2004; Darke, 1988; Humphreys & Revelle, 1984) and vigilance was expected to be lower (e.g., Mahoney et al., 2007).

Concerning exercise-induced fatigue, previous research indicates that there might be different effects of moderate arousal induced through exercise on different types of tasks. Arousal theory suggests that more attention demanding tasks are more susceptible to exercise-induced performance decrements (Hockey & Hamilton, 1983). If this is indeed the case, than we expect a decrease in cognitive performance after exercise (e.g., Mahoney et al., 2007, Tomporowski, 2003) but not necessarily in shooting performance (e.g., Vickers & Williams, 2007). Furthermore, we aimed to provide a first step in unraveling the combined effects of anxiety and exercise-induced fatigue for this group. We reasoned that if exercise-induced fatigue indeed has a different effect on cognitive and shooting performance, consequently combined effects might also be different. On cognitive measures the negative effects of anxiety and exercise-induced fatigue might add up (additive effect), whereas in the shooting task exercise-induced fatigue might compensate for the negative effects.

Method

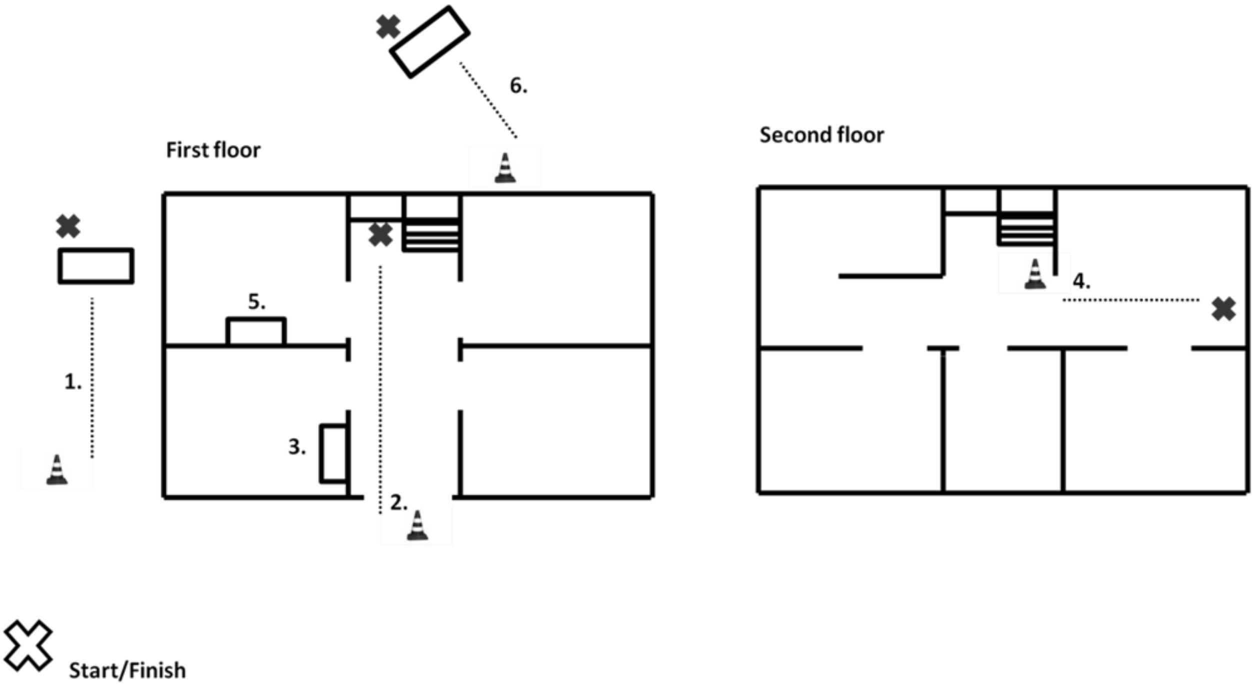
The experiment was conducted with approval of the institutional ethics review board. Given the involvement of firearms, all people involved (experimenters and participants) attended a safety briefing on arrival at the military training village where the experiment took place. Furthermore, a military instructor was present and responsible for the firearms at all times during the experiment.

Participants

Twenty-two male soldiers of a battalion of armored infantry with a mean age of 21 years (*SD* = 1.8) participated in the experiment. Soldiers were randomly divided into a low-fatigue group, that performed the field track in a rested state, and a high-fatigue group, that performed the field track after high-intensity exercise. Both the low- and high-fatigue group had a mean serving experience of 3 years (*SD* = 0.5). Prior to the start of the experiment, participants were informed about the procedure and provided written informed consent. Participants completed the Dutch version of the A-trait scale of the State-Trait Anxiety Inventory (STAI, Van der Ploeg, Defares & Spielberger, 1980). The mean trait scores of the low-fatigue group (*M* = 34.0, *SD* = 6.6) did not significantly differ from the mean score of Dutch male college students (*M* = 36.1, *SD* = 8.4, Van der Ploeg et al., 1980), *t*(10) = 1.06, *p* = 0.314. The mean trait scores of the high-fatigue group (*M* = 31.82, *SD* = 5.34) were lower than the norm, *t*(10) = 2.66, *p* = 0.024. These results indicate that participants had no extraordinary tendency to respond to threatening situations with elevated levels of state anxiety. Moreover, mean trait scores did not differ significantly between participants in the low- and high-fatigue groups, *t*(20) = 0.85, *p* = 0.403. None of the participants reported physical limitations during the time of measurement.

Design

Soldiers performed a multi-task field track of approximately 4 minutes. The field track comprised a circular course in and around a military practice house in which soldiers performed two decision & shoot tasks, two shooting accuracy tasks, two math tasks, a memory task, and a vigilance task (see Figure 5.1). Tasks were performed in a fixed order (1-6 in Figure 5.1). Soldiers were instructed to complete the field track as fast and accurately as possible and to return to the start/finish point as fast as possible. Soldiers that were assigned to the low-fatigue group rested for 10 minutes before the start of a field track, whereas soldiers assigned to the high-fatigue group performed a 10-minute high-intensity running exercise during the same period of time. Within each fatigue group participants performed the field track twice, that is, both in a low-anxiety and in a high-anxiety condition, in a counterbalanced design (for details on the fatigue and anxiety manipulation see below).



a. b.

Figure 5.1a. Map of the ground floor of the practice house. Numbers indicate the task stations, pylons mark the participant's position, and red crosses the opponent's position. (1) 1st decision & shoot task. (2) 1st shooting accuracy task. The cross marks the position of the mannequin (low-anxiety) or live opponent (high-anxiety). (3) 1st math task. (4) 2nd shooting accuracy task. (5) 2nd math task. (6) 2nd decision & shoot task. 5.1b. Map of the first floor of the practice house including the second shooting accuracy task (Station 4).

Tasks

Decision & shoot task

In the decision & shoot task participants were instructed to take position next to the red and white striped pylons at Station 1 and 6 (see Figure 5.1). A closet was positioned at a distance of 5 meters from the participant from behind which an opponent appeared six times shortly after another. The opponent either put his hands in the air to surrender (friendly) or pointed a gun at the participant (hostile). In case the opponent pointed a gun at them, participants were instructed to take a shot at the white laminated target (28 x 28 cm) that was attached to the chest of the opponent (see Figure 5.2) as fast and accurately as possible. In case the opponent surrendered, they were not supposed to shoot the opponent. Decision performance was assessed using signal detection theory (Green & Swets, 1966; Macmillan & Creelman, 1990) by calculating the following measures: the correct-decisions-to-shoot ratio (defined as the number of correct decisions to shoot divided by the total number of decisions), the false-shot ratio (or false alarm ratio, defined as the number of times that a participant shot a surrendering, or 'friendly', opponent divided by the total number of times the participant actually had to shoot), the fail-to-shoot ratio (or false rejection ratio, defined as the number of times that a participant failed to shoot a ‘hostile’ opponent that directed a gun at him divided by the total number of times the participant did not have to shoot), the sensitivity index d’, and the response bias c. Shooting performance was assessed through the percentage of hits in cases participants were supposed to shoot.

Figure 5.2. The opponent in the decision & shoot task. Left: pointing his weapon. Right: surrendering.

Shooting accuracy task

At Station 2 and 4 participants were instructed to shoot at three targets that were attached to both upper legs (20 x 28 cm) and the chest (28 by 28 cm) of an opponent that stood in a hallway at a distance of 5 meters of the participant. This task was derived from a Dutch law enforcement officer’s shooting task and was chosen as it provides a realistic, though controllable, way to measure shooting accuracy on different targets (Nieuwenhuys & Oudejans, 2011). The opponent was either a dummy or a real opponent depending on the anxiety condition (see Figure 5.3). In the shooting accuracy task, participants took cover behind a doorpost, stepped into the door opening, took a shot on the left leg, right leg, and chest of the opponent, after which they took cover again and immediately repeated the whole sequence, resulting in a total of six shots. All shooting was performed with a Colt M16A3 rifle which was modified for firing 9 mm colored soap cartridges (Simunition®, FX Marking Ammunition). Opponents wore full protective clothing. Participants wore an overall, a helmet, and face, neck, and groin protection. Performance on the shooting accuracy task was assessed through the percentage of hits.

Figure 3. The opponent in the shooting accuracy task. Left: low-anxiety condition. Right: high-anxiety condition.

Math task

Station 3 and 5 comprised the math tasks (see Figure 5.1). The math problems were printed on sheets of paper and placed on a table. Participants were instructed to write down as many answers as possible within 1 minute. An hourglass was used to keep the time. There were two versions of the math problems, which were used in a counterbalanced design. Math problems were a combination of multiplications and additions using only numbers between 3 and 10 (for example: 6 x 8 + 4). Performance on the math task was assessed through the total number of answers, the number of incorrect answers, and the percentage of correct answers that participants wrote down.

Memory task

Prior to the start of the field track, a list of 11 groceries was shown to the participant for one minute. Participants were instructed to remember as many groceries as possible throughout the field track. Performance on the memory task was assessed as the number of groceries (0 - 11) that participants remembered after finishing the field track.

Vigilance task

To assess participants' vigilance, a detection task was added to the task battery. Five items of a soldier's equipment (e.g., cup, army shovel, weapon belt, tape, and an ammunition box) were situated along the route inside the practice house. Before participants started the field track they were instructed to be aware of any soldier equipment lying around in the house. The vigilance task thus required participants to sustain their attention throughout the field track. If participants encountered one of these objects they had to call the object's name out loud which was registered by one of the experimenters. As participants performed the field track twice, each item was placed in two different but similar locations, in a counterbalanced design. Performance on the vigilance task was assessed through the number of objects detected (0 - 5).

Manipulation of anxiety and exercise-induced fatigue

Anxiety manipulation

In the high-anxiety condition, the decision & shoot and shooting accuracy tasks were equal to that in the low-anxiety condition except that now participants were at risk of being shot with Simunition® rounds. Simunition® rounds inflict considerable pain and bruising upon impact and have been proven to cause increased levels of perceived anxiety in previous studies (e.g., Nieuwenhuys & Oudejans, 2011; Oudejans, 2008). Concerning the decision & shoot task, while in the low-anxiety condition opponents aimed their gun at the participants, in the high-anxiety condition opponents were instructed to actually shoot back at the participant (in two out of six hostile trials to limit the number of hits). In the shooting accuracy task, the dummy that was set as the target in the low-anxiety condition was replaced by a real opponent that returned fire (again in two out of six hostile trials) at the participant in the high-anxiety condition (see Figure 5.2).

Besides Simunition®, ego-stressor methods were also used to induce anxiety. First, a competitive element was introduced. Prior to the experiment participants were instructed that they had to perform the field track twice. There was a performance round in which points would be rewarded depending on how well they performed the tasks (corresponding to the high-anxiety condition) and their score would be compared to that of their colleagues. The points collected in the performance round would be processed into a score list that was sent to the participants two days after the experiment had ended. The other round would be a practice or control round (corresponding to the low-anxiety condition). Furthermore, during the math task additional pressure was induced by the presence of an audience. Whereas in the low-anxiety condition participants performed the math task alone in a room, in the high-anxiety condition two experimenters were present and watched the participant fill out the answers. Finally, in the math task an hourglass was used to induce time pressure. In the low-anxiety condition the hour glass was not present in the room. However, in the high-anxiety condition the hour glass was situated next to the participant to remind him of the limited time left to execute the task.

Exercise-induced fatigue

Exercise-induced fatigue was manipulated through a 10-minute high-intensity running exercise. Two pylons were situated at a distance of approximately 50 m apart. Participants were instructed to run up and down between the pylons as often as possible within 10 minutes. The number of rounds was registered and compared among participants to motivate them to run as fast as possible. Colleagues were present to cheer on the participant.

Manipulation checks

Perceived anxiety

To check whether the anxiety manipulation was successful, we used an anxiety scale called the anxiety thermometer. The anxiety thermometer is a visual-analogue scale that consists of a 10-cm continuous scale ranging from 0 (not anxious at all) to 10 (extremely anxious). It was validated by Houtman and Bakker (1989) and was successfully used in earlier experiments (e.g., Oudejans & Pijpers, 2009, 2010). Directly after both anxiety conditions participants completed the anxiety scale.

Perceived mental effort

Increases in perceived anxiety are often accompanied by increases in the amount of mental effort that participants invest in task execution (e.g., Nibbeling, Daanen, Gerritsma, Hofland, & Oudejans, 2012; Nibbeling, Oudejans, & Daanen, 2012). Participants' perceived mental effort was determined using the Rating Scale of perceived Mental Effort (RSME, Zijlstra, 1993). This vertical scale ranges from 0 (absolutely no effort) to 150 mm (most effort ever). The RSME has been proven valid and reliable by Veltman and Gaillard (1993) and has been used successfully in previous studies (e.g., Eaves, Hodges, & Williams, 2008; Nieuwenhuys & Oudejans, 2011; Oudejans & Pijpers, 2009, 2010). The RSME scale was completed directly after each condition.

Exercise-induced fatigue

Participants' fatigue level was assessed through ratings of perceived exertion (RPE) and heart rate. RPE was assessed with the Borg scale (Borg, 1982). The Borg Scale ranges from 0 to 10, with 0 reflecting no exertion at all and 10 corresponding to maximal exertion. Directly before and after each condition participants indicated their ratings of perceived exertion on the RPE scale. In addition, heart rate was assessed using a heart rate monitor (Polar RS400). The average heart rate that was measured during the field track was reported as the outcome measure.

Procedure

Measurements were divided over five days. Participants arrived in groups of five or six and all measurements of one participant were performed on the same day. Upon arrival, participants were informed about the procedure, gave their written informed consent, and completed the STAI. They also completed an anxiety thermometer, and studied the RPE and RSME scales to become familiar with them. Subsequently, they put on the heart rate monitor and protective clothing and were randomly assigned to one of the fatigue groups.

Before the experiment started, all tasks were explained while participants walked through the field track with one of the experimenters. After the walk-through the actual experiment began. All participants were tested individually. Participants started the field track in either the low- or high-anxiety condition. In the high-anxiety condition, participants were reminded that their scores would be compared to that of their colleagues, whereas in the low-anxiety condition they were reminded that this was a control round. Moreover, they were instructed to be aware of any soldier equipment lying around in the house and to call the object's name out loud when they found one. Participants received the grocery list and were given one minute to study the list. Subsequently, participants that were assigned to the high-fatigue group performed a 10-minute fatiguing drill, whereas participants in the low-fatigue group sat on a chair for 10 minutes. Then, the participant was quickly equipped with protective gear, received his rifle, and started the field track. One experimenter followed the participant through the course with a video camera. After approximately 4 minutes participants had performed all tasks and returned back at the start/finish point. Participants were seated on a chair and immediately indicated their heart rate, rate of perceived exertion, perceived mental effort, and completed an anxiety scale. Next, they were instructed to write down all groceries they remembered.

Participants that were assigned to the high-fatigue group then performed the 10-minute running exercise again, whereas participants in the low-fatigue group rested for 10 minutes. Subsequently, participants started in the second condition (low- or high-anxiety depending on the first round). Directly after the second anxiety condition, participants indicated their heart rate, rate of perceived exertion, perceived mental effort, and perceived anxiety again. At the end of the experiment, participants were fully debriefed and thanked for cooperating.

Statistics

Anxiety scores, RSME, RPE, heart rate, task performance, sensitivity d', response bias c, and performance times were submitted to 2 x 2 (Fatigue [low-fatigue, high-fatigue] x Anxiety [low-anxiety, high-anxiety]) ANOVAs with repeated measures on the second factor. Correct-decisions-to-shoot ratios of 1.0 and 0.0 were adjusted using the 1/2N rule for non-parametric data (Macmillan & Kaplan, 1985). Significant differences were assessed using Bonferroni post-hoc tests. Results with p-values of $\leq .05$ were considered statistically significant. Effect sizes were calculated using Cohen's f with 0.10 or less, about 0.25, and 0.4 or more, representing small, moderate, and large effect sizes, respectively (Cohen, 1988). When sphericity was violated, Greenhouse-Geisser corrections were applied. As there was only one significant interaction this is also the only one we reported. All other interactions had Fs < 1.65 and ps > 0.217.

Results

Manipulation check

A complete overview of the means and *SD*s of the manipulation checks is provided in Table 5.1.

Anxiety scores

There was a significant main effect of Anxiety on anxiety score, $F(1,20) = 13.00$, $p = 0.002$, $f = 0.80$. Participants perceived themselves as more anxious in the high- compared to the low-anxiety condition, 95% CI [0.4, 1.6]. No significant effects of Fatigue were found, $F(1,20) = 0.07$, $p = 0.789$, 95% CI [-1.7, 2.3].

Invested mental effort

There was also a significant main effect of Anxiety on RSME, *F*(1,20) = 8.38, *p* = 0.009, *f* = 0.65. RSME scores were significantly higher in the high- compared to the low-anxiety condition, 95% CI [2.2, 13.8]. No significant effects of Fatigue were found, *F*(1,20) = 1.27, *p* = 0.273, *f* = 0.25, 95% CI [-29.4, 8.8].

Perceived exertion

There was a significant main effect of Anxiety on RPE , *F*(1,20) = 4.32, *p* = 0.051, *f* = 0.47, as well as a significant main effect of Fatigue, *F*(1,20) = 7.62 *p* = 0.012, *f* = 0.62. Participants tended to perceive more exertion in the high- than the low-anxiety condition, 95% CI[0.0, 1.0], and the high-fatigue group perceived significantly more exertion than the low-fatigue group, 95% CI [0.4, 2.8] (see Table 5.1).

Heart rates

There was a significant main effect of Anxiety, *F*(1,18) = 16.13, *p* = 0.001, *f* = 0.94, and Fatigue, *F*(1,18) = 21.42, *p* < 0.001, *f* = 1.01 on heart rate. Heart rates were significantly higher during the high- than the low-anxiety condition, 95% CI [3, 10] and in the high-fatigue group compared to the low-fatigue group, 95% CI [15, 41].

Thus, results on anxiety scores, heart rate, RSME, and perceived exertion indicate that both the anxiety manipulation and the fatiguing protocol were successful.

Table 5.1 Mean values for anxiety, perceived mental effort and exertion, and heart rate (including standard deviations) during a military field track.

	Group	Condition	
		Low Anxiety	High Anxiety
		M (SD)	*M (SD)*
Manipulation check			
Anxiety Score (0-10)	LF	3.7 (1.9)	5.0 (2.9)
	HF	4.2 (2.2)	5.0 (2.0)
RSME (0-150)	LF	61.6 (18.2)	67.3 (25.2)
	HF	69.6 (23.9)	80.0 (21.7)
RPE (0-10)	LF	3.1 (0.9)	3.6 (1.4)
	HF	4.6 (1.6)	5.2 (1.7)
Heart rate (bpm)	LF	124 (17)	131 (18)
	HF	153 (11)	158 (7)

Note. LF = low fatigue, HF = high fatigue, RSME = Rating Scale of perceived Mental Effort, RPE = Rating of Perceived Exertion, HR = heart rate.

Decision & Shoot task

A complete overview of the means and *SD*s of the results of the decision & shoot task is provided in Table 5.2.

Correct–decisions-to-shoot ratio

There was no main effect of Anxiety, $F(1,19) = 0.20$, $p = 0.666$, $f = 0.10$, 95% CI [-0.03, 0.05], or Fatigue, $F(1,19) = 2.05$, $p = 0.171$, $f = 0.35$, 95% CI [-0.01, 0.05], on the percentage of correct decisions to shoot. Thus, participants made just as many correct decisions to shoot in all conditions (see Table 5.2).

False-shot ratio (false alarms)

The main effect of Anxiety on the percentage of false shots approached significance at the $p \leq .05$ level, $F(1,17) = 4.07$, $p = 0.060$, $f = 0.48$. The percentage of false shots tended to be higher in the high- than the low-anxiety condition, 95% CI [0.00, 0.05]. No significant effects of Fatigue were found, $F(1,17) = 0.16$, $p = 0.691$, 95% CI [-0.03, 0.04]. Thus, it seems that anxiety led soldiers to more often pull the trigger in case of a surrendering opponent.

Fail-to-shoot ratio (false rejections)

Concerning the fail-to-shoot category, there was no significant effect of Anxiety, $F(1,17) < 0.01$, $p > 0.80$, $f < 0.01$, 95% CI [-0.02, 0.02]. However, a significant effect of Fatigue was found, $F(1,17) = 5.37$, $p = 0.033$, $f = 0.56$, with the high-fatigue group having a higher percentage fail-to-shoot decisions than the low-fatigue group, 95% CI[0.00, 0.03]. This indicates that after fatiguing exercise soldiers more often failed to shoot when they should have shot a threatening opponent.

Sensitivity

There was no significant effect of Anxiety, $F(1,17) = 1.45$, $p = 0.245$, $f = 0.29$, 95% CI [-0.1, 0.5], or Fatigue, $F(1,17) = 0.74$, $p = 0.403$, $f = 0.20$, 95% CI [-0.2, 0.5] on sensitivity index (d’). Thus, participants could distinguish between targets (threatening opponents) and non-targets (surrendering opponents) equally well in both groups and both conditions.

Response bias

The effect of Anxiety on the response bias (c) just failed to reach significance at the $p \leq .05$ level, $F(1,17) = 3.62$, $p = 0.074$, $f = 0.47$, 95% CI [0.0, 0.3], and was not affected by Fatigue, $F(1,17) = 0.31$, $p = 0.586$, $f = 0.14$, 95% CI [-0.1, 0.2]. Thus, in the high-anxiety condition soldiers tended to be more prone to shoot.

Percentage of hits

The main effect of Anxiety on percentage of hits in the decision & shoot task failed to reach significance at the $p \leq .05$ level, $F(1,17) = 3.18$, $p = 0.092$, $f = 0.44$, 95% CI [-1.5, 18.4], and did not differ between fatigue groups, F(1,17) < 0.01, $p = 0.995$, 95% CI [-26.6, 30.5]. However, there was a significant interaction effect between Anxiety and Fatigue, $F(1,17) = 4.58$, $p = 0.047$, $f = 0.52$. Post-hoc analyses revealed that participants in the low-fatigue group had a lower percentage of hits in the high-anxiety condition than in the low-anxiety condition ($p = 0.015$), whereas for participants in the high-fatigue group shooting performance did not differ between the anxiety conditions ($p = 0.800$). No significant effects of Fatigue were found in the low- ($p = 0.498$) or high-anxiety condition ($p = 0.500$). These results indicate that anxiety negatively affected shooting performance, but only in the low-fatigue group.

Table 5.2 Mean values for performance on the decision & shoot task (including standard deviations) during a military field track

	Group	Condition	
		Low Anxiety	High Anxiety
		M (SD)	*M (SD)*
Decision & Shoot task			
Correct-decisions-to-shoot ratio	LF	0.97 (0.04)	0.96 (0.08)
	HF	0.97 (0.04)	0.93 (0.08)
Fail-to-shoot ratio (false rejections)	LF	0.00 (0.00)	0.00 (0.00)
	HF	0.02 (0.04)	0.02 (0.04)
False-shot ratio (false alarms)	LF	0.02 (0.04)	0.03 (0.04)
	HF	0.01 (0.03)	0.05 (0.06)
Sensitivity (d')	LF	3.2 (0.4)	3.2 (0.4)
	HF	3.2 (0.5)	2.9 (0.7)
Response bias (c)	LF	-0.04 (0.1)	-0.1 (0.2)
	HF	0.04 (0.2)	-0.1 (0.2)
% of hits	LF	48.1 (15.5)	29.6 (30.9)
	HF	40.0 (40.2)	41.6 (31.7)
Task Duration (sec)	LF	13.9 (2.0)	14.8 (2.6)
	HF	15.2 (5.1)	15.0 (5.3)

Shooting accuracy task

A complete overview of the means and *SD*s of the results of the shooting accuracy task, math task, memory task, and vigilance task is provided in Table 5.3**.**

Percentage of hits

There was a significant main effect of Anxiety on the percentage of hits in the shooting accuracy task, $F(1,20) = 60.61$, $p < 0.001$, $f = 1.73$. Percentage of hits was approximately 35% lower in the high- than in the low-anxiety condition, 95% CI[23.6, 40.8]. No significant effects of Fatigue on shooting accuracy were found, $F(1,20) = 0.04$, $p = 0.845$, 95% CI [-18.0, 21.8].

Math task

Total number of answers

The number of answers showed no significant main effects of Anxiety, $F(1,20) = 1.18$, $p = 0.291$, 95% CI [-2.9, 0.9], or Fatigue, $F(1,20) = 0.40$, $p = 0.535$, 95% CI [-8.6, 4.6] (see Table 5.3).

Number of incorrect answers

Although there were no effects of Anxiety or Fatigue on the total number of answers, there was a significant main effect of Anxiety on the number of incorrect answers, $F(1,20) = 6.80$, $p = 0.017$, $f = 0.58$, whereas the effect of Fatigue approached significance, $F(1,20) = 3.29$, $p = 0.085$, $f = 0.40$. Participants wrote down more incorrect answers in the high- compared to the low-anxiety condition, 95% CI [0.3, 2.6], and the high-fatigue group tended to provide more incorrect answers than the low-fatigue group, 95% CI [-0.2, 2.5].

Percentage of correct answers

As the number of answers provided differed among participants we also introduced percentage of correct answers as an outcome variable. Percentage of correct answers revealed a significant main effect of Anxiety, $F(1,20) = 12.55$, $p = 0.002$, $f = 0.80$, whereas there was no significant effect of Fatigue, $F(1,20) = 0.54$, $p = 0.472$, 95% CI [-14.6, 7.0]. Participants' percentage of correct answers was lower in the high- compared to the low-anxiety condition, 95% CI [3.3, 12.8].

In sum, anxiety negatively affected participants' performance on the math task. Moreover, exercise-induced fatigue also seemed to negatively influence math performance.

Memory task

Number of correct answers

Analyses of memory task scores revealed neither main effects of Anxiety, $F(1,20) = 0.02$, $p = 0.901$, 95% CI [-12.8, 14.5], nor of Fatigue, $F(1,20) = 0.10$, $p = 0.757$, 95% CI [-18.9, 14.0]. Thus, neither anxiety nor exercise-induced fatigue seemed to have an influence on performance in the memory task. Participants indicated that the second time this task was performed was influenced by the first time (the memory tasks interfered). Therefore, we investigated order effects for this variable. ‘Order’ was added as a between subjects factor in the analyses and showed a significant interaction with Anxiety, $F(1,20) = 6.98$, $p = 0.016$, $f = 0.59$. Post-hoc analyses indicated that participants that started in the low-anxiety condition tended to give more correct answers in the low- than the high-anxiety condition, $p = 0.063$, whereas participants that started in the high-anxiety condition tended to give more correct answers in the high- than the low-anxiety condition, $p = 0.093$. Due to this order effect no conclusions could be drawn from these data in the discussion section.

Vigilance task

Number of detected objects

There was no significant effect of Anxiety on the number of objects detected in the vigilance task, $F(1,20) < 0.01$, $p > 0.80$, 95% CI [-0.7, 0.7]. Neither were there significant effects of Fatigue, $F(1,20) = 0.66$, $p = 0.426$, 95% CI [-0.4, 1.0]. The number of detected objects was very low in general and over half of the participants did not detect any objects (see Table 5.3).

Times

Track Times

There was no significant effect of Anxiety on the time to complete the field track, $F(1,20) = 1.06$, $p = 0.315$, $f = 0.23$, 95% CI [-6.3, 18.6]. Neither was there a significant effect of Fatigue, $F(1,20) = 0.12$, $p = 0.738$, $f = 0.10$, 95% CI [-14.3, 19.9].

Table 5.3 Mean values for performance on shooting accuracy, the math task, memory task and vigilance task (including standard deviations) during a military field track

	Group	Condition	
		Low Anxiety	High Anxiety
		M (SD)	*M (SD)*
Shooting accuracy task			
% of hits	LF	67.4 (24.9)	32.6 (26.2)
	HF	66.7 (22.7)	37.1 (23.7)
Task Duration (sec)	LF	8.6 (3.6)	6.8 (3.2)
	HF	6.2 (1.7)	6.4 (2.8)
Math task			
Nr of answers	LF	17.9 (7.1)	19.1 (7.9)
	HF	20.1 (8.6)	20.9 (7.3)
Nr of false answers	LF	1.9 (1.6)	2.8 (1.9)
	HF	2.6 (2.3)	4.6 (2.2)
% correct answers	LF	87.8 (9.1)	82.2 (13.1)
	HF	86.4 (13.4)	75.9 (16.5)
Memory task			
% of correct answers	LF	52.1 (23.7)	61.2 (24.4)
	HF	59.5 (22.0)	48.8 (45.8)
Vigilance task			
Nr objects (0-5)	LF	0.6 (1.4)	0.5 (0.8)
	HF	0.7 (1.1)	0.9 (1.1)
Track time (sec)	LF	244.0 (12.2)	241.5 (20.1)
	HF	247.1 (25.6)	240.0 (15.0)

Discussion

We investigated the effects of anxiety and exercise-induced fatigue on cognitive and shooting performance of Dutch infantry soldiers in a realistic field study. Participants performed a field track that included shooting tasks and a variety of cognitive tasks (decision making, math problems, memory, and vigilance). Anxiety was manipulated through the risk of being shot with military training ammunition, through time pressure, competition, and an audience that was present during task execution. To manipulate exercise-induced fatigue half of the participants performed a running exercise prior to the field track. Results on anxiety scores, perceived mental effort, perceived exertion, and heart rate indicate that both the anxiety manipulation and the fatiguing protocol were successful.

Whereas previous studies found negative effects of anxiety on performance in sports and policing (e.g., Nibbeling et al., 2012a; Oudejans, 2008; Wilson et al., 2009) the effects of anxiety on operational behavior of soldiers remained unclear. Results of the current study indicate that anxiety can also evoke decrements in cognitive and shooting performance in infantry soldiers, even after several years of military training (most participants had 3 years experience). In the high-anxiety condition, participants showed a performance decrement that was substantial (drop in shooting accuracy between 20% and 40%) and comparable to previous studies in for example police officers (drop around 32%, Nieuwenhuys & Oudejans, 2010; around 16%, Nieuwenhuys & Oudejans, 2011; around 22%, Oudejans, 2008). An explanation for this large drop might be that despite their military training, none of the participants had been on an actual mission or had had much training in a training village. To be better able to maintain shooting accuracy under threatening circumstances, we recommend soldiers to train their shooting behavior under anxiety. In previous studies, police officers that practiced their shooting behavior under stressful circumstances learned to focus their visual attention sufficiently long on the targets to maintain a high shooting accuracy, also with anxiety (Nieuwenhuys & Oudejans, 2011*)*. Moreover, skilled performance appears to be more resilient under anxiety as skills tend to get automated over practice, thereby reducing the attentional resources necessary for task performance (e.g., Brown & Carr, 1989). Hence, more attentional resources are available to deal with the effects of anxiety. Inexperienced police officers, who still need to pay much attention to task execution, tend to be more prone to negative effects of anxiety than experts (Suss & Ward, 2010).

Besides shooting accuracy, cognitive performance was also negatively affected by anxiety. In the math task, the percentage of correct answers was eight percent lower in the high-anxiety (79% correct) than in the low-anxiety condition (87% correct). In addition, anxiety caused decrements in participants' decision making skills. When anxious, soldiers more often decided to shoot ($p = 0.060$) when confronted with a surrendering opponent. The results on response bias indicate that this increase in false shots was due to a higher tendency towards shooting ($p = 0.07$) when participants were anxious. These results should be interpreted with caution as they just failed to reach significance on the $p \leq .05$ level. The large accompanying effect sizes ($f = 0.48$ and $f = 0.47$) indicate that this is mainly due to a lack of power. The field-based nature of the current study did not allow measuring large numbers of participants. Contrary to laboratory studies, studies that aim to approach real-world settings are complex and time consuming. However, it is important that these studies are performed as lab results do not always generalize to the real world (e.g., Dicks et al., 2010; Eccles et al., 2007; Mann et al., 2007). Therefore, although the results on shooting decisions just failed to reach significance, we feel that they are particularly meaningful to mention.

The findings on the decision task correspond with findings of Nieuwenhuys et al. (2012) who assessed similar effects in police officers facing an opponent in a video lab setting. The police officers responded more rapidly, made more incorrect decisions and consequently shot more surrendering opponents, when confronted with a so called shoot-back canon that created higher levels of anxiety. Compared to the police officers, the soldiers in the current study were relatively accurate in their decision making. Police officers made 11% decision errors in the low-anxiety and 18% in the high-anxiety condition, whereas soldiers in the current study showed 1% and 4% false shots in these conditions. Possibly, this discrepancy was due to the difference in experimental setting in the two studies with a rapid succession of over forty trials per condition in the study by Nieuwenhuys et al. (2012) and two sets of only six trials in the current study. Furthermore, in the current study, participants were confronted with live opponents, while in the police study participants had to respond to an opponent that appeared in a video. People may be more careful to actually pull the trigger when confronted with a real person than with a video projection. The current findings seem to support the occurrence of mismatches between results from laboratory settings and more realistic environments (Dicks et al., 2010; Mann et al., 2007). We recommend future research to increase their effort in designing experimental setups that more closely resemble military reality to advance this area of research (see also, Ward et al., 2008). Furthermore, although relatively small, the encountered decreases in decision accuracy should not be overlooked. In the heavy and variable circumstances soldiers commonly have to work in, even small decreases in cognitive performance can already make the difference between life and death (e.g., Wilson et al., 2007).

Regarding the vigilance task, hardly any of the equipment hidden in the practice house was detected in either of the conditions. It should be noted, however, that our instruction to perform the field track as accurately and fast as possible made realistic execution of the vigilance task unlikely. Generally, soldiers are instructed to invest considerable time in exploring the terrain and caution has priority over speed. However, in the current experimental setup time to perform the field track was one of the performance measures. Consequently, more research is needed to unravel the effects of anxiety and exercise-induced fatigue on soldiers' vigilance.

Whereas anxiety had major effects on cognitive and aiming performance, exercise-induced fatigue only evoked minor changes. This was possibly due to the relatively small size of the fatigue groups. Whereas anxiety was investigated using a repeated-measures design ($N = 22$), exercise-induced fatigue was investigated using a between-subjects design ($N = 11$ per group). Despite the relatively small group size, results indicate that in the decision & shoot task participants in the fatigued group significantly more often failed to shoot when they were supposed to. Thus, whereas anxiety evoked an increased tendency to shoot at surrendering suspects, exercise-induced fatigue affected soldiers' decision making in the opposite direction. Additional debilitative effects of exercise-induced fatigue on cognitive performance were observed in the math task. Fatigued participants tended to provide more incorrect answers than their non-fatigued counterparts. Results on the math task should be interpreted with caution as they only approached significance on the $p \leq 0.05$ level ($p = 0.085$). Contrary to the results on cognitive performance, shooting performance seemed to benefit from the increased arousal levels. In the decision & shoot task, participants in the fatigued group managed to maintain their shooting accuracy under anxiety, whereas accuracy decreased significantly by 40% in the rested group. Apparently, whether exercise-induced fatigue was beneficial or detrimental to task performance depended on the task at hand.

These findings support arousal theories. In line with Hockey and Hamilton (1983), the cognitive tasks seem more susceptible to the imposed fatigue level than the shooting tasks. Heart rates during execution of the field track ($M = 156$, $SD = 9$) suggest that participants performed the field track in an aroused state rather than a heavily fatigued state. Whereas heavy fatigue may have a negative effect on far aiming performance, arousal as a result of moderate exercise can actually improve far aiming performance. In line with the inverted-U hypothesis, Vickers and Williams (2007) showed that arousal that was evoked through cycling initially facilitated rifle shooting in biathlon athletes, whereas maximal exhaustion was counterproductive to shooting accuracy. On the other hand, the arousal encountered in the current study appeared severe enough to negatively affect cognitive performance. We suggest that a possible explanation for this difference is that the optimal performance point on the inverted-U curve depends on the processing demands of the specific task (e.g., Féry, Ferry, Vom Hofe, & Rieu, 1997; Hockey & Hamilton, 1983). The arousal encountered here might therefore have corresponded with the optimal performance point for the shooting task. However, at the same arousal level, the performance point for the demanding cognitive tasks may have already passed this optimal state, resulting in decreased performance. In sum, the current findings provide more insight into the effects of anxiety and exercise-induced fatigue on soldier performance, separately and in combination. In line with previous studies on policing, soldiers' cognitive and shooting performance was negatively affected by anxiety (e.g., Nieuwenhuys & Oudejans, 2010; Nieuwenhuys et al., 2012; Oudejans, 2008). Moreover, we provided indications that whether exercise-induced fatigue is beneficial or detrimental to soldier performance depends on the task at hand. Increased arousal levels due to exercise can prevent shooting accuracy from deteriorating under anxiety, although performance on more attention demanding tasks, such as mathematical performance and decision accuracy, was negatively affected by fatigue. It is important for future research to investigate the possibilities to prevent soldier performance from deteriorating under fatiguing and threatening circumstances.

6

A multi-agent computational model of the effects of anxiety on human performance

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Abstract

A major challenge in developing complex behavior models is dealing with all the factors that can influence human behavior and performance. To cope with this complexity the Capability-based Human-performance Architecture for Operational Simulation (CHAOS) was developed. In the current study, we examined whether complex human behavior can be modeled using three basic assumptions within CHAOS: behavior is goal-directed or stimulus-driven, 2) behavior requires resources, 3) resources are distributed according to priority of behavior. The assumptions were examined by building a model of the effects of anxiety and multi-tasking on different types of human performance. The model was based on data from human subject experiments and in line with the basic premises of attentional control theory (ACT, Eysenck et al., 2007). Results indicated that anxiety affected outcome parameters in a similar way in the model as in the human subjects. Moreover, the model results matched the empirical data very closely. This suggests that the resource based modelling approach in CHAOS has merit.

Keywords: attentional control theory, anxiety, CHAOS, human behavior modelling

Introduction

Computational human behavior models (HBMs) are powerful tools that help to gain insight into human behavior under various external and internal conditions. The development of valid simulations allows us to predict performance under circumstances that are hard or impossible to create in an experimental setting. The major challenge in developing complex behavior models is dealing with all factors that can influence human behavior and performance. For instance, in a military context, behavior and performance are influenced by the mission objective and various internal (emotional, cognitive, and physiological) and external (e.g., threat assessment, weather, terrain) factors.

To cope with this complexity the Capability-based Human-performance Architecture for Operational Simulation was developed (CHAOS, Ubink et al., 2008). CHAOS is a multi-agent system in which each agent represents a specific type of behavior. Underlying CHAOS are some general assumptions. The first assumption is that humans are either driven by goals they want to achieve, or by events that require them to react. In other words, human behavior is either goal-directed, or stimulus-driven. The second assumption is that humans require resources, such as attention, fine and gross motor control, or physical work capacity, for behavior. The agents in the CHAOS framework depend on the availability of these resources in sufficient amounts to perform their behavior. When insufficient resources are available, for instance as a result of stress or multi-tasking, performance will degrade. The third assumption is that resources are distributed according to the priority of the different behaviors. This makes CHAOS suitable to model the effects of multi-tasking and performance degradation under stress.

There are studies that provide support for the separate assumptions, such as the need of resources for behavior (e.g., muscle physiology, e.g., Edwards et al., 1972), or that behavior can be goal-directed or stimulus-driven (e.g., Corbetta & Shulman, 2002). However, building a model that simulates the complete human at the level of muscle cells and neurons is so complex that it is currently not feasible nor desirable. With the CHAOS architecture, we intend to abstract out the details, and build a model that incorporates the general principles of human behavior. The aim of the current study is to investigate whether these abstractions are acceptable. In other words, can we model complex human behavior by modeling human beings as a collection of resources responding to stimuli without including the models of neural and physiological processes from which these resources and stimuli originate?

The assumptions underlying CHAOS are not far-fetched and in line with common sense. Furthermore, previous applications of CHAOS in simulations in the military, fire-fighting and traffic domains, provided results with good face validity (e.g., Ubink et al., 2008). However, validation of the framework is required. Unfortunately, an all-embracing constructive validation of a generic modelling framework such as CHAOS, is simply not feasible. A feasible approach is to implement a specific model and compare this model with empirical data. This approach allows evaluating whether the model produces results similar to those found in human subject experiments.

To this aim, we selected a theory that is of interest to the application for which CHAOS was originally developed and is still used, namely simulations of military operations, traffic behavior and behavior of first responders. In these domains, task execution requires high levels of attention and task conditions can be complex (e.g., several tasks are performed simultaneously) and threatening. A theory that captures these aspects for the cognitive tasks that are of importance in these settings (e.g., vigilance, decision making) is the Attentional Control Theory (ACT, Eysenck et al., 2007). ACT describes the mechanisms through which anxiety can affect cognitive functioning. However, besides cognitive tasks, people also perform (perceptual-) motor tasks, such as shooting, marching, or running. Recently, ACT is extended for perceptual-motor tasks by Nieuwenhuys and Oudejans (2012), resulting in the integrated theory of anxiety and perceptual-motor performance. This extended theory relies heavily on the central tenets of the ACT, but integrates mechanisms through which anxiety affects movement execution. The central tenets of ACT are very similar to the assumptions in the CHAOS framework. According to ACT, anxiety can elicit a shift in attention from goal-directed to stimulus-driven, thereby increasing the distribution of attentional resources towards threat-related stimuli, at the expense of attention allocated to the task. Similarly, CHAOS distinguishes goal-directed and stimulus-driven behavior. Moreover, in CHAOS a central part is played by resources, of which ACT's attention is a specific example. Also, CHAOS provides a mechanism to model stressors and to convert stress in performance effects. These similarities make CHAOS suitable to develop a computational model of ACT.

Next, we selected an empirical dataset on the effects of anxiety and multi-tasking on human performance (Nibbeling et al., 2012). Three behaviors could be distinguished: running, dart throwing, and worrying. Moreover, attention was selected as the main resource in the model. Using ACT, the dependence of the behavioral components on the attentional resource was defined. Then, a subset of the empirical data was used to quantify the consumption of the attentional resource by these behaviors. The effects of anxiety and multi-tasking on performance were simulated with the resulting model and the data that the model produced were compared to the empirical data.

In the following section the CHAOS framework is explained in more detail. Subsequently, the ACT (including its extension to perceptual-motor performance) is outlined. In the method section, we describe the study that provided the empirical data. Also, the process of defining and implementing the model within the CHAOS framework is explained. Finally, the comparison of the model and empirical data is presented and the results are discussed.

The CHAOS framework

As mentioned previously, the CHAOS framework is based on the idea that humans are either driven by goals they want to achieve, or by events that require them to react (Ubink et al., 2008). It is assumed that all (latent) behaviors are in constant competition with each other. At stake in this competition are the resources that are required to perform these behaviors. Examples of these resources are: visual perception, reasoning, fine and gross motor control, or physical work capacity.

The different behaviors are implemented as software agents, called *demons*, analogous to the demons in the pandemonium model of letter recognition by Selfridge (1958). Each demon in CHAOS represents a specific (latent) behavior. The goal of these demons is to activate the latent behavior that they represent. In order to do this, they need to obtain the resources required to perform that specific behavior. However, other demons may also require these resources. The demons are therefore engaged in a competition for resources. This competition is won by the demons that have the highest “priority”.

The demons themselves are responsible for determining their priority. The demons communicate their importance by *shrieking*: the louder a demon shrieks, the more important it is. Shrieking levels can range from 0 (i.e., no shrieking) to 1 (i.e., highest priority to consume the resources required for this particular behavior). The shrieking level of goal-directed demons is usually fixed and reflects the priority of the goal or task. The shrieking level of stimulus-driven demons is dynamic and depends on internal and external factors. For instance, in a military simulation, when an enemy is detected, immediate action is required. The demon that models the appropriate reactive behavior (e.g., taking cover and returning fire) will shriek out louder than the other demons in the competition in this situation. Consequently, it can consume the resources it requires to take cover and return fire.

At first sight, this may seem to be a winner-takes-all approach in which only the most important demon performs its behavior. However, other demons can still get a chance to execute their behavior, because the winning demon does not necessarily use all resources. Thus, if two demons are not conflicting with regard to the required resources, they can execute their behaviors simultaneously. Note that it is possible that not enough resources are available for optimal performance of both behaviors, in which case sub-optimal multi-tasking may occur.

In CHAOS, stressors are represented as stimulus-driven demons that monitor a specific (set of) variable(s). Such a “stress demon” can affect resource levels but may also, just as a regular demon, have behaviors associated to it. For example: anxiety could be modelled by a specific demon. This anxiety demon may monitor an anxiety inducing factor, such as approaching hostile troops (in case of a military simulation). When this situation occurs, the demon will start shrieking. As the situation gets scarier (e.g., the opponents start shooting), the shrieking will increase. As soon as the demon starts shrieking, it can start consuming resources that are required by other demons for (optimal) behavior. If that is the case, then stress has resulted in behavioral changes or performance degradation.

The central algorithm in CHAOS is essentially a four-step procedure that is repeated each simulation time-step:

1) Resource levels are initialized. The status of the resources may be affected as a result of the previous time step in the simulation, so the resources are set to their initial state.
2) Shrieking levels are updated. Stimulus-driven demons with dynamic shrieking levels can adjust their shrieking level according to the current state of the world and/or the entity.
3) Stress-demons affect resources. The demons that represent some form of stress can affect (increase or decrease) resource levels, according to their shrieking level, i.e., according to the stress level.
4) Demons attempt to perform behaviors. Starting with the demon that is shrieking loudest, each demon checks if the resources it requires are available. The demon takes these resources if they are available and performs its behavior. If the resources are not available the demon does nothing. This is repeated until each demon has had a chance to collect resources and perform its behavior.

The effects of anxiety on performance

Attentional Control Theory (ACT, Eysenck et al., 2007) is a theory that describes the mechanisms through which anxiety can affect cognitive functioning. Similar to CHAOS, ACT ties in with the suggestion that a person's (attentional) resource capacity is limited (Eysenck et al., 2007). Moreover, ACT states that anxiety can elicit a shift in attention from goal-directed to stimulus-driven. In other words, the distribution of attentional resources towards threat-related stimuli is suggested to increase at the expense of attention allocated to the task. When too much attention is consumed by anxiety, not enough attentional resources remain available to be invested in the task at hand. Consequently, task execution is expected to suffer. For example, the threat of an upcoming hostile attack can distract a soldier's attention to worries about the situation and its consequences (stimulus-driven attention). As a result, he or she might fail to pick up crucial information from the environment (goal-directed attention). Consequently, the soldier might misinform colleagues, decide on the wrong course of action, trip, or collide with hazards.

Findings that support ACT are also available for perceptual-motor performance (e.g., for handgun shooting, Nieuwenhuys & Oudejans, 2010; skeet shooting, Causer et al., 2011; and penalty kicks, Wilson et al., 2009b). This progressive insight led to a recent extension of ACT (the integrated theory of anxiety and perceptual-motor performance, Nieuwenhuys & Oudejans, 2012). Nieuwenhuys and Oudejans (2012) suggest that similar mechanisms underlie anxiety induced changes in perceptual-motor and cognitive performance. They argue (p. 23) "that through its effect on attention, anxiety affects the degree to which we are able to control our movements". For example, during a shooting exercise police officers paid more attention to the opponent's gun and less to the target areas they were supposed to hit when they were confronted with a threatening suspect that shot back at them (Nieuwenhuys & Oudejans, 2011). Consequently, no appropriate adjustment movements could be made on the available perceptual information (e.g., about the location of the target) and shooting accuracy was affected in the threatening situation (Nieuwenhuys & Oudejans, 2011).

The extension of Nieuwenhuys and Oudejans (2012) relies heavily on the central tenets of the ACT. According to ACT, anxiety does not necessarily lead to a decrease in task performance. Task execution can also become less efficient. When anxious, people might for example execute a task slower in order to maintain performance, a so called speed-accuracy tradeoff (e.g., Beilock, Bertenthal, Hoerger, & Carr, 2008). Moreover, as another strategy to avoid a decrease in performance, people can increase the mental effort they invest in the task. Comparable performance that is achieved by exerting greater effort can also be considered less efficient. In general, effects of anxiety on task efficiency are suggested to be considerably greater than on performance (Eysenck et al., 2007). However, when the attentional demands of anxiety become too large, eventually not only efficiency but also performance will deteriorate. Finally, besides anxiety, also multi-tasking is suggested to form a possible threat to task performance. Adverse effects of anxiety on a task are suggested to be larger when a secondary task imposes demands on attentional resources. In sum, the effects of anxiety on performance depend on (1) the combined attentional demands of the tasks and stressors at hand and (2) the availability and utilization of additional resources.

Method

In this section, we explain how we used the empirical data and ACT to build a model in the CHAOS framework. In Figure 6.1 an overview of the four steps that were taken, is presented. The steps were as follows:

1) Performance data were collected from an empirical study with human subjects in which anxiety and multi-tasking were manipulated (Nibbeling et al., 2012). In this study, ANOVAs were used to test the results for significant effects of anxiety and multi-tasking.
2) The assumptions within CHAOS and ACT were used to develop a model in the CHAOS framework. The tasks and independent variables in the model are taken from Step 1. Then, the dataset collected in Step 1 was randomly split into two subsets. One of the subsets, the model set ($n = 9$), was used to build the model and define the configuration parameters for the demons, resources, and behaviors. The application of the second subset, the test set ($n = 10$), is described in Step 4.
3) A simulation of the model was run, with the same manipulations that were used in the empirical studies.
4) Finally, to validate the model, ANOVAs were performed to compare the model output with the test set. Additionally, ANOVAs were performed to determine if the manipulations had similar effects on the model as on the human subjects. .

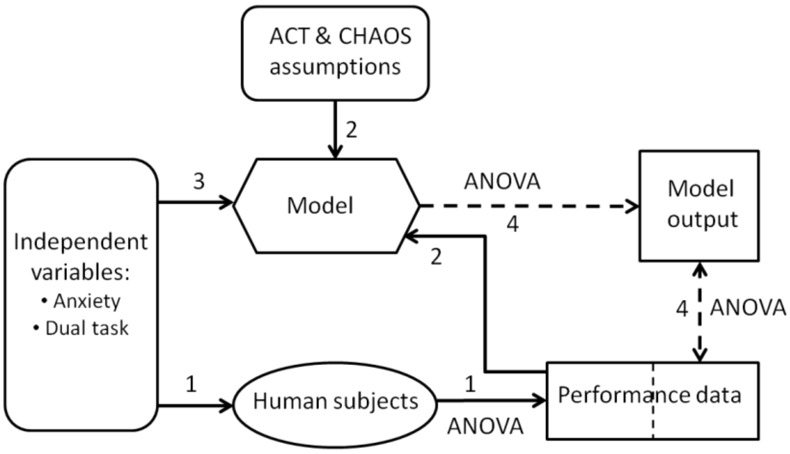

Figure 6.1. The methodology followed to develop and evaluate the model.

The various steps that were taken are explained in more detail in the remainder of the paper.

Empirical studies

The data that were used to build the model were obtained from an empirical study that investigated the effects of anxiety on running with and without a dual task (Nibbeling et al., 2012). More precisely, the influence of anxiety on running and aiming (dart throwing), separately and combined, was investigated. Anxiety was manipulated through height. Subjects ran on a treadmill on the ground (low-anxiety condition) and on a high, narrow scaffold (high-anxiety condition) in a counterbalanced design (see Figure 6.2). During the 10-minute running test, subjects were solely running at a constant speed for the first 8 minutes. Subsequently, in the final two minutes a dual task setting was created in which subjects performed a secondary dart throwing task while running. Oxygen uptake, heart rate, gait parameters (e.g., stride length and contact times), dart throwing accuracy, and dart times were measured continuously throughout the experiment and were compared between the anxiety conditions. Furthermore, it was assessed whether subjects invested more mental effort in the task when they were anxious and whether differences in their focus of attention were present by means of a questionnaire.

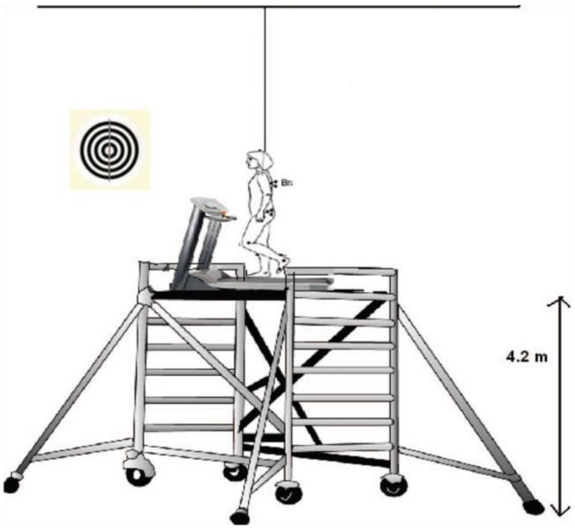

Figure 6.2. Experimental setup Nibbeling et al. (2012).

In line with ACT, results showed that subjects perceived the tasks as requiring more effort when they were anxious. Moreover, subjects indicated that anxiety distracted their attention away from task-relevant information towards worries about falling off the scaffold. This increase in worries was accompanied by a more rigid running pattern and consequently subjects' oxygen uptake increased. In other words, running became less efficient high on the scaffold. In addition, accuracy and efficiency on the dart throwing task decreased under anxiety, which was indicated by lower dart scores and longer dart throwing times.

Studies that present their findings to be in line with predictions from distraction theories, such as ACT, are usually concerned with cognitive or perceptual-motor tasks as these often have high attentional demands. However, the study by Nibbeling et al. (2012) indicates that anxiety does not only affect cognitive and aiming tasks but also tasks that rely heavily on the aerobic system through changes in attention.

Model development

The general approach to developing a model in the CHAOS framework is to start with the identification of behaviors and resources that should be included. After that the demons that represent the behaviors are implemented. This includes quantifying how the demon's "shrieking level" varies with other variables. Another important aspect is quantifying the dependencies of the demon on resources and defining how performance will degrade if resources are limited.

Figure 3 gives an overview of the model that was created in CHAOS. From left to right, it shows the resources, the demons with their behaviors, and the model outputs. These components and their interactions are further described in the following sections.

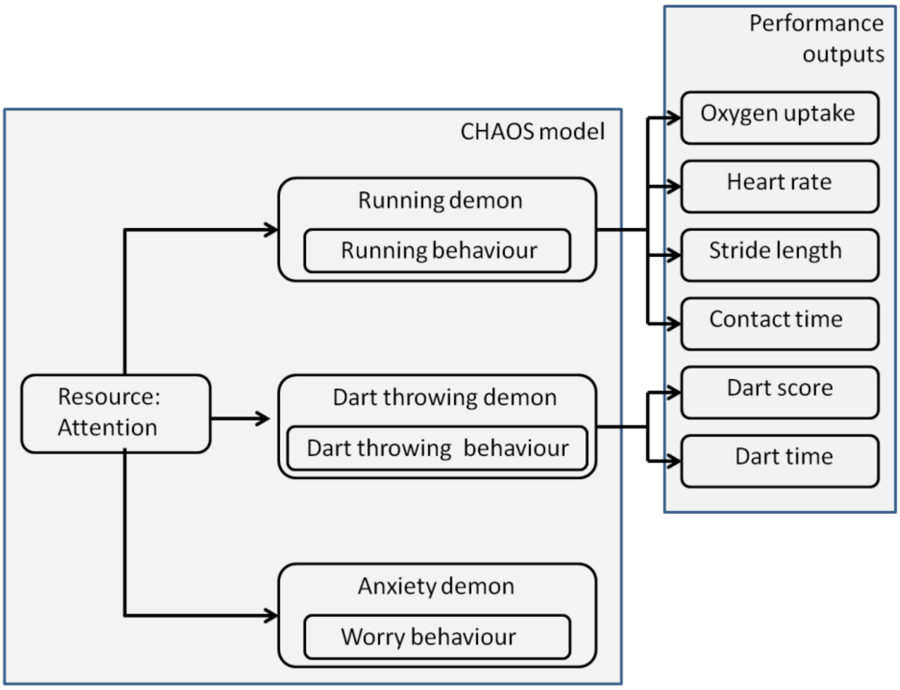

Figure 6.3. Overview of the model that explains the effects of anxiety in the running and aiming experiment.

Behaviors

For the current model, all the tasks in the empirical study were implemented as goal-directed demons. Also, following ACT, an anxiety demon with "worry" behavior was included. In terms of CHAOS, this demon is a "stress demon" that is stimulus-driven and that consumes attentional resources. This leads to the distinction of the following behaviors:

- Running
- Dart throwing
- Worrying

Resources

When the behaviors that are to be modelled are defined, the next step is to think about the *resources* that are required in the model. The starting point here is the function that a resource should play in the model. There are only two possible functions. The first function is to modulate task performance, e.g., task performance as a function of an attentional resource. The second function is to prevent that two conflicting, mutually exclusive, behaviors are executed simultaneously, e.g., walking and riding a bike. For this specific model, only the first function is relevant, and only "Attention" was defined as a resource. Attention is consumed by anxiety through worry and is needed for all tasks.

Demons

Demons were created to represent the goal-directed and stimulus-driven behaviors (running, dart throwing, and worrying) in the CHAOS framework. Demons can behave differently dependent on the context they are in. They are defined by resource levels, inputs from external systems, and internal parameters. The next section describes how the resource consumption of the various demons was determined. Then the following sections describe the different demons and their role in modelling behavior.

Resource consumption

The resource consumption of the various demons was determined by looking at all combinations of tasks and stressors that resulted in performance effects in the human subjects in the study by Nibbeling et al. (2012). In line with the empirical results and ACT, we assumed that resource requirements exceeded resource availability in these cases. These cases are underlined in Table 1 that lists the hypothesized resource requirements. In this table, attentional resource requirements are indicated by a number between 0 and 1, with 1 representing the total capacity.

In those cases in which the resource requirements by the different demons exceeded the total capacity, a limitation of resource consumption was assumed, as indicated in Table 2. Each change in efficiency or performance in the human subjects provides insight into the resource consumption of the behaviors and the stressors involved. Based on this, a hypothetical resource distribution was established that was consistent with the effects that were observed in the experiment by Nibbeling et al. (2012).

Table 1. The hypothesized attentional requirements of the different behaviors in each condition.

Hypothesized attentional *requirements*					
		Run		Run + Dart	
	Ideal	Low	High	Low	High
Worry	0.75	0.00	0.75	0.00	0.75
Running	0.30	0.30	0.30	0.30	0.30
Dart throwing	0.80	0.00	0.00	0.80	0.80
Total	**1.85**	**0.30**	<u>**1.05**</u>	<u>**1.10**</u>	<u>**1.85**</u>

Table 2. The hypothesized distribution of the total attentional capacity over the different behaviors in each condition.

	Hypothesized attentional *usage*			
	Run		Run + Dart	
	Low	High	Low	High
Worry	0.00	0.75	0.00	0.50
Running	0.30	0.25	0.20	0.15
Dart throwing	0.00	0.00	0.80	0.35
Total	**0.30**	**1.00**	**1.00**	**1.00**

Running

A constant shrieking level of 1.0 (highest) was chosen for the running demon to represent the fact that the subjects in the experiment could not stop running (the treadmill was set at a fixed speed). This allows this particular demon to take priority over any other demon. The running behavior is modelled as a controller of oxygen uptake, heart rate, stride length, and contact times. Equations indicating the dependency of the running variables on attention were calculated from the model set of the empirical data (see Figure 6.1). x represents the amount of attention consumed by the running task:

Oxygen uptake	$f(x) = -1290x + 2619.5$,
Heart rate	$f(x) = -78x + 184.8$,
Stride length	$f(x) = 36x + 145.3$,
Contact time	$f(x) = -132.8x + 317.8$

Dart throwing

Dart scores and dart times were calculated based on the amount of attention consumed by the dart throwing demon (see Table 2). If not enough attention was available the dart throwing variables were affected negatively. The following equations represent the dependency of the dart throwing variables on attentional resources, as computed from the empirical data:

Dart score	$f(x) = 0.9x + 4.5$
Dart times	$f(x) = -1.3x + 5.4$, where x represents the amount of consumed attention.

Model validation

To assess whether the simulated data were similar to the empirical data, 2 x 2 x 2 (Anxiety [low, high] x Task [single, dual] x Data Type [empirical, simulated]) ANOVAs with repeated measures on the first two factors were performed on the following parameters: oxygen uptake, heart rate, stride length, and contact times. The between-subjects factor ‘Data Type’ compares the model outputs to the test set of the empirical dataset (see Figure 6.1).

Next, 2 x 2 (Anxiety [low, high] x Task [single, dual]) ANOVAs with repeated measures on both factors were performed on the simulated oxygen uptake, heart rate, stride length, and contact time parameters to determine whether the Anxiety and Task manipulations had similar effects on the simulated data as on the human subjects in Nibbeling et al. (2012). Furthermore, as the dart task was only performed in the dual task condition, a paired samples *t*-test was performed to assess the effects of Anxiety on the dart scores and dart times.

Effect sizes were calculated using Cohen’s *f* with 0.10 or less, about 0.25, and 0.4 or more, representing small, moderate, and large effect sizes, respectively (Cohen, 1988). Observed statistical power is indicated by , with 0. 2 or less, about 0.5, and 0.8 or more, representing small, moderate, and large statistical power.

Results

Comparison simulated data with empirical data

The ANOVA showed that there was no significant difference between the two data sets (empirical and simulated) for any of the variables described above, *F*s < 1.65, *p*s > .151. The test set of the empirical data set contains the average oxygen uptake, heart rate, stride parameters and dart throwing variables for each of the 10 participants in the test set of the experiment. The modelled data set consisted of 100 runs of these variables that resulted from the model (based on the model set of the empirical data).

Model results

Oxygen uptake

Simulated oxygen uptake showed a significant main effect of Anxiety, *F*(1, 99) = 3.96, *p* = .049, *f* = 0.20, = 0.50, and Task, *F*(1, 99) = 24.62, *p* < .001, *f* = 0.50, > 0.99. Consistent with the results of Nibbeling et al. (2012; *F*s > 5.55, *p*s < .030, for the effects of Anxiety and Task), more oxygen was consumed in the high- compared to the low-anxiety condition and in the dual task compared to the single task condition (see Figure 6.4).

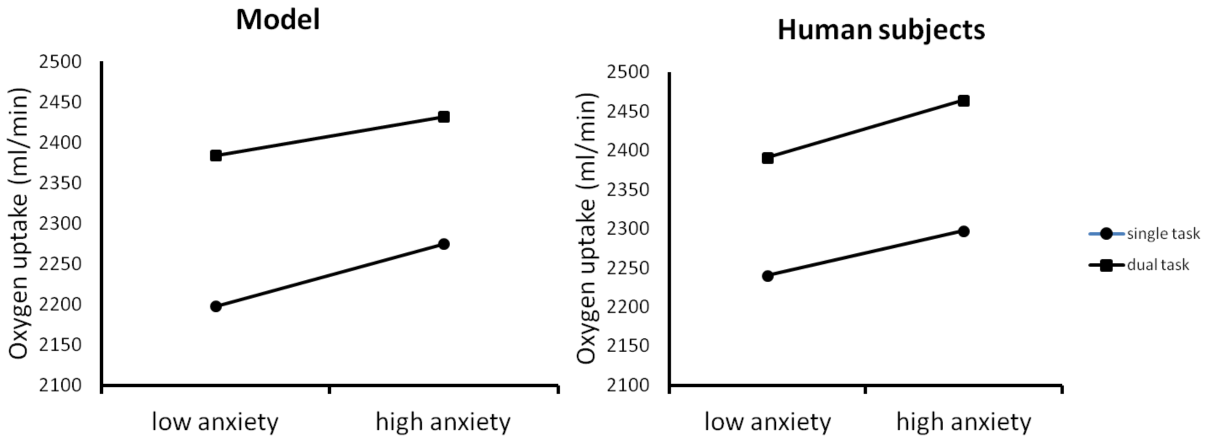

Figure 6.4. The graph on the left shows the oxygen uptake values produced by the model. The graph on the right shows the results for oxygen uptake of Nibbeling et al. (2012).

Heart rate

Simulated heart rates showed significant main effects of Anxiety, *F*(1, 99) = 15.48, *p* < .001, *f* = 0.40, = 0.97, and Task, *F*(1, 99) = 10.38, *p* = .002, *f* = 0.32, = 0.89, and a significant anxiety/dual task interaction, *F*(1, 99) = 5.45, *p* = .022, *f* = 0.23, = 0.63. Post-hoc analyses revealed that in the low-anxiety condition heart rates were higher in the dual than the single task condition, *p* < .001, whereas in the high-anxiety condition there was no difference between tasks, *p* = .455 (see Figure 6.5). Moreover, in the single task condition, heart rates were higher in the high- than in the low-anxiety condition, *p* < .001, whereas in the dual task condition there was no difference between anxiety conditions, *p* = .145. Results are partly in line with those of Nibbeling et al. (2012) who only found significant main effects of Anxiety and Task, *F*s > 6.55, *p*s < .022.

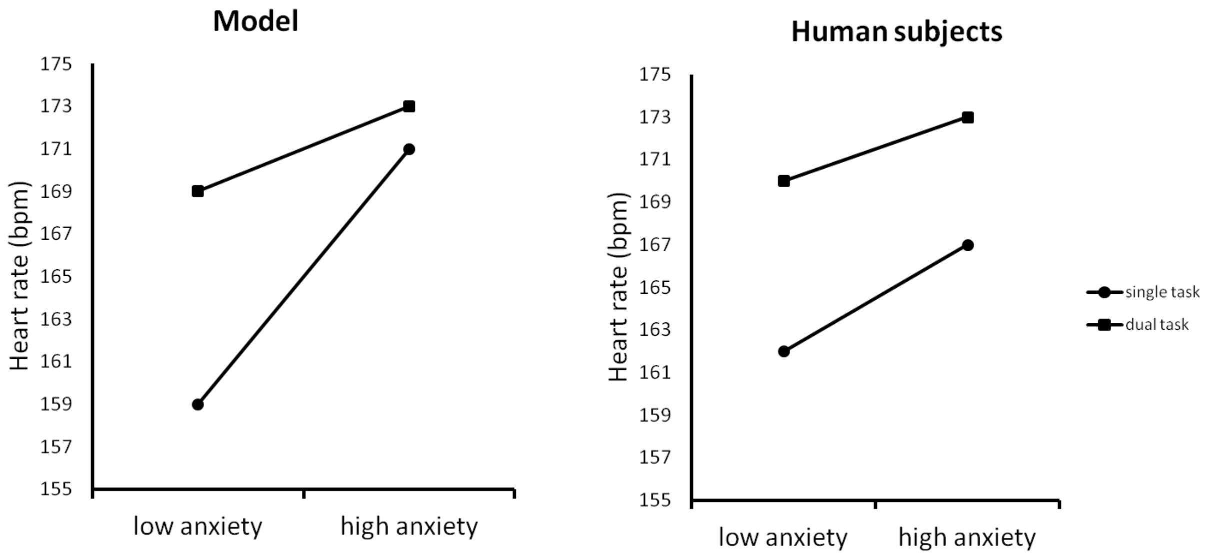

Figure 6.5. Heart rates produced by the model (left) and heart rates of the human subjects in Nibbeling et al. (2012) (right).

Stride parameters

Simulated contact times and stride lengths showed significant main effects of Anxiety, *F*s(1, 99) > 11.65, *p*s < .002, *f*s > 0.30, > 0.96, and Task, *F*s(1, 99) > 8.77, *p*s < .004, *f*s > 0.38, > 0.95. Results are consistent with those of Nibbeling et al. (2012, *F*s > 7.46, *p*s < .014, for the main effects of Anxiety and Task). In both the empirical and modelled data mean stride length was shorter in the high- than in the low-anxiety condition. Moreover, mean stride length was shorter in the dual task than in the single task condition. Also, contact times were longer in the high-anxiety and the dual task condition (see Figure 6.6 and 6.7).

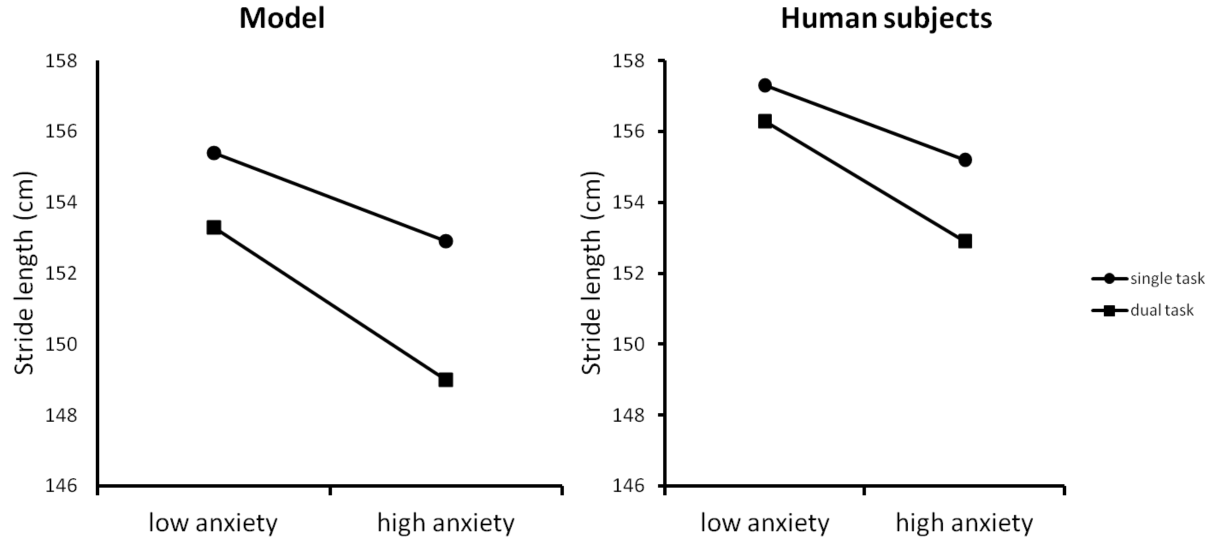

Figure 6.6. Stride lengths produced by the model (left) and stride lengths of the human subjects in Nibbeling et al. (2012) (right).

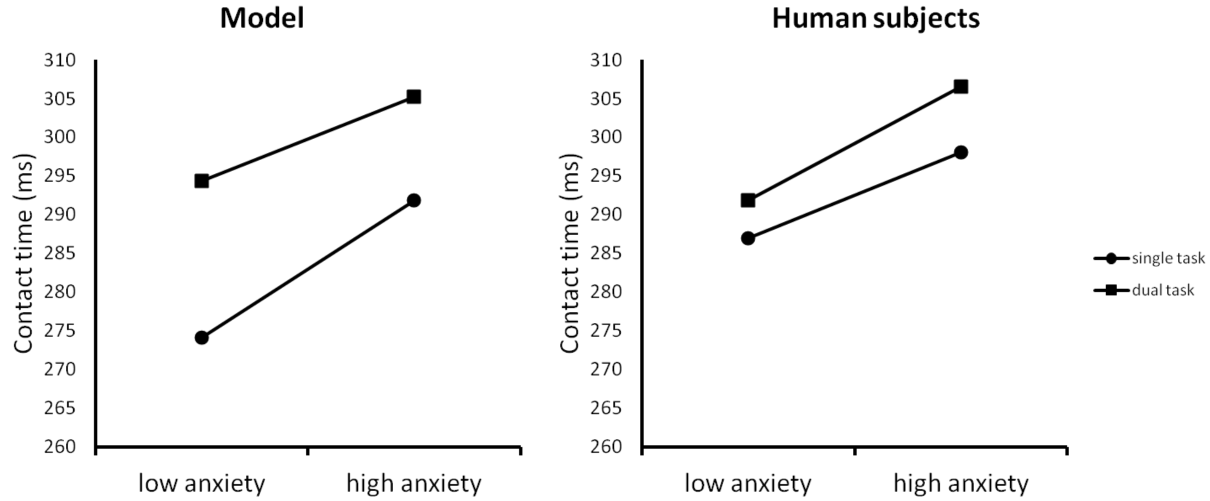

Figure 6.7. Contact times produced by the model (left) and contact times of the human subjects in Nibbeling et al. (2012) (right).

Dart score and dart time

In the simulation, dart throwing variables showed a significant main effect of Anxiety, *t*(99) = 2.47, *p* = .015, and, *t*(99) = 6.15, *p* < .001, for dart score and dart time, respectively. These results are in line with the findings of Nibbeling et al. (2012, *t*(18) = 2.26, *p* = .036, and, *t*(18) =

2.94, *p* = .009). In both the empirical and modelled data the mean dart scores were lower and dart times were longer in the high- than in the low-anxiety condition (see Figure 6.8 and Figure 6.9).

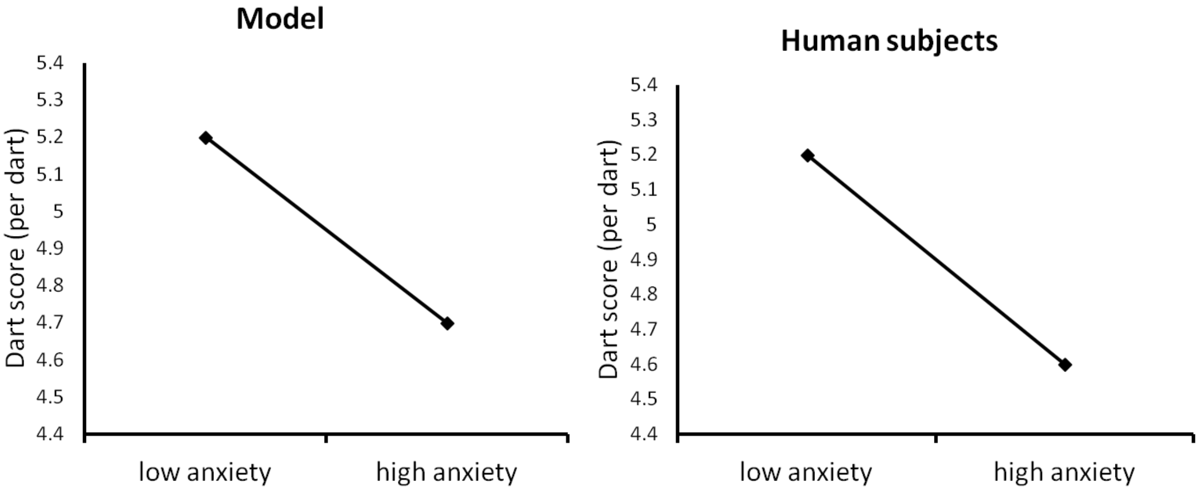

Figure 6.8. Dart scores produced by the model (left) and dart scores of the human subjects in Nibbeling et al. (2012) (right).

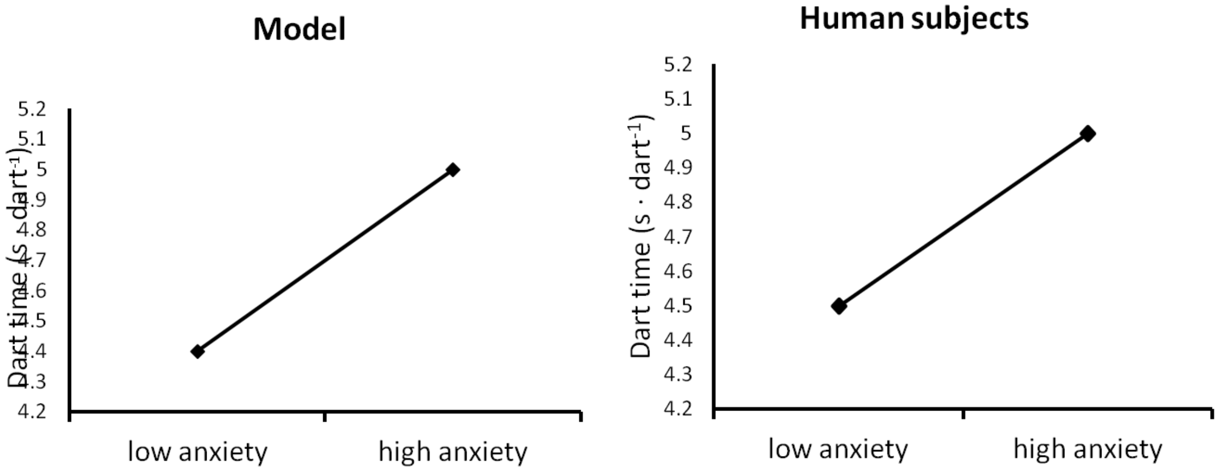

Figure 6.9. Dart times produced by the model (left) and dart times of the human subjects in Nibbeling et al. (2012) (right).

Discussion

In the current study we aimed to examine the basic assumptions within the CHAOS framework. To this end, we developed a model of the effects of anxiety on human performance, based on empirical data and in line with the central tenets of attentional control theory (ACT, Eysenck et al., 2007). Results indicated that the simulated data matched the empirical data closely. Moreover, in the model, anxiety affected oxygen uptake, heart rate, stride parameters, and dart throwing accuracy in a similar way as in the human subjects in the study by Nibbeling et al. (2012). This suggests that the resource-based modelling approach in CHAOS has merit.

The first CHAOS assumption we presented was that human behavior is either goal-directed or stimulus-driven. In the study by Nibbeling et al. (2012) this assumption is supported by the tasks that the human subjects were instructed to perform: running and dart throwing, which are typical examples of goal-directed behaviors. On the other hand, the worry behavior, resulting from anxiety, was not goal-directed but stimulus-induced. In the model, we were able to simulate the dynamics between these behaviors with stimulus-driven and goal-directed demons and the associated resource distribution. In the model, the priority of stimulus-driven behaviors is directly related to the magnitude and importance of the stimulus. This means that resource distribution and the associated behavior and performance effects can vary with external or internal stimuli.

Another assumption in CHAOS is that human resources, such as attention, are required for behavior. When insufficient resources are available, for instance as a result of stress or multi-tasking, task efficiency, and eventually performance may degrade. Moreover, it is assumed that resources are distributed according to the priority of the different behaviors that are performed. In the study by Nibbeling et al. (2012), running efficiency decreased in the high-anxiety condition or when running was combined with dart throwing. This decrease in running efficiency was indicated by an increase in oxygen uptake and a less efficient stride pattern. Following ACT, it was assumed that the decrease in running efficiency was due to the consumption of attentional resources by worry and/or dart throwing. A possible solution to this resource conflict could be to lower the running speed or to stop running altogether. However, since the subjects in the experiment by Nibbeling et al. (2012) were not able to influence running speed, running efficiency suffered instead. The fact that running was mandatory was simulated by a constant and maximal shrieking level (highest priority) for the running demon. The oxygen consumption and stride parameters of the running demon were modelled as a function of attentional resources. Results indicate that we were able to simulate these effects with the components available in the CHAOS framework. In line with the empirical results, the model showed an increased oxygen uptake and heart rate as well as a less efficient simulated stride pattern when the anxiety increased and/or when dart throwing while running.

Furthermore, the model was successful in simulating the effects of anxiety on dart throwing efficiency and performance. In the study by Nibbeling et al. (2012) subjects' dart throwing efficiency and performance were negatively affected by anxiety. Human subjects needed more time to throw the darts and dart scores were lower in the high- than in the low-anxiety condition. In CHAOS, demons that represent stress, such as anxiety, can affect performance by consuming resources. Consequently, worry behavior (as a result of anxiety) consumed attentional resources needed for dart throwing in the high-anxiety condition. Contrary to running, subjects were not obliged to perform the dart task at a fixed speed. As a result, with part of attentional capacity consumed by worries, they performed the dart task slower in the high- than in the low-anxiety condition. This was, however, apparently not sufficient to prevent performance from deteriorating. The dart times and scores of the dart throwing demon were modelled as a function of attentional resources. In line with the results by Nibbeling et al. (2012), this resulted in increased dart times and decreased dart scores when the worry demon was activated.

The resource-based modelling that is applied in the CHAOS framework contributes to the development of computational Human Behavior Models (HBMs) as it allows for the combination of cognitive and physical aspects of behavior, by using resources as an the interface between various behaviors and stressors. Previous research on human behavior representation (HBR) has mostly focused on cognitive aspects of human behavior, such as decision making and planning (e.g., Kushleyeva, Salvucci, Lee, 2005; Martin & Ellis, 2012; Morrison, 2003). Also, the field of human performance modelling focuses on performance effects in either the cognitive (e.g., Silverman, 2001) or physical (Meador & Hill, 2011; Morton, Fitz-Clarke, & Banister, 1990; Wray & Laird, 2003) domain. However, in practice, cognitive, (mental) and physical aspects are often intertwined and influence human behavior simultaneously. Being able to combine the cognitive and physical domains is thus an important property of the CHAOS framework that adds to the practical applicability of the model in for instance, the military, fire-fighting, and traffic domains.

A consideration with regard to the use of data from these kinds of full-body human experiments is that the data sets are usually relatively small. At least, when compared to experiments that focus on cognitive factors and use computer task that can be easily repeated many times. Especially, when, as in the current study, half the dataset is used to build the model and the other half is used to test the model against. As these full-body human experiments comprise extensive planning, organization, and execution the number of subjects measured is typically around 15 to 20. In the current study, all model results matched the empirical results except for the heart rate data. As 19 human subjects were assessed in this study, this is likely due to the limited statistical power. Although, in such full-body human experiments the assessment of large groups of subjects is often not feasible, we recommend including complex human behavior data (that combines both physical/cognitive behavior) in future models. Experimental setups that closely resemble the complexity of human behavior in practice would advance this area of research.

A major challenge that arose from the presented resource-based modelling approach was to define suitable resources and the consumption of these resources by the various behaviors and stressors. First of all, the approach we followed in this study was a pragmatic one in which we defined as few resources as necessary to replicate the observed results. To this end, only attention was selected as a resource. Of course, in reality, more resources are required for running and dart throwing. However, for this specific model there is no reason to include additional resources. Second, the distributions of the required and consumed attentional resources over the different behaviors that are presented in Table 1 and 2 were derived from the performance effects in the human subjects in Nibbeling et al. (2012). Following ACT, these performance effects were suggested to depend on the availability of attentional resources. Consequently, equations were formulated to represent the dependency of the output variables (oxygen uptake, heart rate, and stride parameters) on attention. Third, it was assumed that the outcome variables vary linearly with the amount of attention used. Subjective measures used by Nibbeling et al. (2012) support the idea that the changes in task efficiency and performance were the result of a decrease of attention directed at the task. However, further research with more explicit measures of attention (e.g., gaze behavior, EEG) is needed to provide more insight into the distribution of attentional resources when performing under stressful circumstances or multi-tasking.

Although further research is recommended to improve the model for this specific task setting, the comments mentioned above should not be considered limitations of the presented modelling approach. New, extended equations from future research can easily be built in into the CHAOS framework. Moreover, one of the major advantages of the CHAOS framework is that it is not restricted to a particular task setting. CHAOS can be used for a variety of different purposes and can be extended with different tasks and stressors (e.g., vigilance tasks, anxiety resulting from speaking in public). The behaviors and stressors only interact with each other through resources, leading to generic, flexible models. However, more research is required to examine the applicability of the framework to different domains with their specific tasks and stressors.

Finally, it should be pointed out that the created model is not the only possible solution. Due to the many parameters involved and the limited amount of data, some assumptions needed to be made during the model development. This is why we have tried to also base the model on an existing theory of anxiety, the ACT. Since the ACT has been successfully used in explaining the effects of anxiety on task performance and has not been falsified, we believe that the approach used in this model is the best method of explaining the observed anxiety effects that is currently available to us.

In sum, the CHAOS framework was used successfully to model effects of anxiety and multi-tasking on human performance. These results indicate that the modelling approach in CHAOS has merit. We were able to simulate these effects with the basic assumptions that are available in the CHAOS framework: 1) human behavior is either goal-directed or stimulus-driven, 2) human resources are required for behavior and when insufficient resources are available task efficiency and/or performance will degrade, 3) resources are distributed according to the priority of the different behaviors that are performed. Due to these basic assumptions, the CHAOS framework allows creating abstractions of complex scenarios and can be used to explain and simulate both the cognitive and physical aspects of behavior. Therefore, the potential applications of the CHAOS framework are numerous. The models that can be implemented in the framework can be used to predict and explain complex behaviors under circumstances that are hard to perform directly, such as severely stressful or fatiguing environments, such as military, fire fighting, or traffic environments.

7

Epilogue

The goal of the present thesis was to gain insight into the separate and combined effects of anxiety and exercise-induced fatigue on operational performance. In the domains of sports and policing, separate effects of these stressors on the performance of (mostly separate) tasks have received considerable attention. However, despite the potentially serious consequences and the commonality of their occurrence, there is little research on how combinations of anxiety and exercise-induced fatigue affect operational performance. Moreover, little is known about the effects these stressors can have on some of the tasks that are inextricably linked to operational performance, such as endurance tasks. Therefore, in this thesis, we aimed to answer the following questions. Does anxiety affect basic aerobic tasks such as running (whether or not combined with a secondary task, **Chapter 2**)? How is far aiming performance affected by anxiety, a secondary cognitive task, and expertise (**Chapter 3**)? Does shooting behavior change when exercise-induced fatigue gradually increases (**Chapter 4**)? What are the combined effects of anxiety and exercise-induced fatigue on soldier's shooting and cognitive performance (**Chapter 5**)? And can these empirical results be used to build simulation models that can predict soldier performance on military missions (**Chapter 6**)? Answers to these questions are provided in the following summary of the main findings and general conclusion. Next, theoretical and practical implications are discussed.

Summary

Anxiety is known to affect cognitive and perceptual-motor tasks, such as far aiming (e.g., Eysenck et al., 2007, Wilson, 2008; Nieuwenhuys & Oudejans, 2012). However, whether and how anxiety affects tasks that rely heavily on the aerobic system remains unclear. **Chapter 2** investigated the influence of anxiety on running and on the combination of running and far aiming. Participants ran on a treadmill near the ground (low-anxiety) and on a high scaffold (high-anxiety) with and without a concurrent dart-throwing task. After both anxiety conditions, participants were asked to indicate their focus of attention during that condition. Results indicated that participants experienced more anxiety high on the scaffold than near the ground and that participants paid more attention to distracting thoughts and worries about falling off the treadmill in the high-anxiety condition. Moreover, anxiety caused participants to run less efficiently, resulting in smaller and more steps, longer contact times, and a higher oxygen uptake. Also, participants performed the dart throwing task less accurate when anxiety was manipulated. Finally, the condition in which running, dart throwing, and anxiety were combined showed the largest values on all kinematic and metabolic variables (except for stride length which showed the lowest value). Together, findings indicate that anxiety can also affect tasks with a large aerobic component, such as running. Furthermore, running, aiming, and anxiety all seem to compete for attentional resources leading to an accumulating effect on running parameters and suboptimal performance when they are combined.

Next, **Chapter 3** investigated the effects of anxiety and a cognitive secondary task on far aiming. Moreover, in addition to anxiety and a secondary task, a third manipulation of attentional resources was induced through expertise. Novice and expert dart players performed a dart throwing task low (low-anxiety) and high (high-anxiety) on a climbing wall, and with or without a concurrent counting backwards task. Participants' gaze behavior was assessed as a measure of (visual) attention. Anxiety evoked a decrease in dart performance, but only for the novices. Counting backwards (secondary task) did not affect performance, which is probably because participants preferred to switch between the dart throwing and the counting task instead of performing them simultaneously. Analyses of participants' gaze behavior indicated that performance decrements were accompanied by shorter final fixations on the target and by fixations that deviated off the target earlier. These findings stress the importance of sufficient time to look at a target and to pick-up the (visual) information that is necessary for successful performance as late as possible. Moreover, the finding that anxiety decreased dart throwing accuracy only for novices, and that novices invested more mental effort in the dual task condition, indicates that anxiety, expertise level, and the secondary task all influenced the amount of attentional resources that are consumed. Peoples' attentional capacity is suggested to be limited, leading to a decrease in efficiency and eventually performance when this capacity is exceeded.

In **Chapter 4**, the effect of gradually increasing exercise-induced fatigue on shooting behavior was examined in a pursue-and-shoot task. Participants ran on a treadmill and chased a target in a virtual environment. They were free to choose when to stop the treadmill and shoot at the target. During the 20 minute-pursuit task participants became gradually more physically fatigued. Analyses of the data showed no changes in shooting performance due to exercise. However, the distance to the target at which participants decided to shoot showed a U-shaped relationship with exercise-induced fatigue. The rating of perceived exertion of 6.5 constituted the lowest point of the U curve, that is, the distance closest to the target. As anticipated, participants stopped running sooner, aimed at the target longer and shot less often, at high levels of exercise-induced fatigue. Findings indicate that physiological parameters influence actual transitions between different actions. Thus, the decision when to shoot (distance to the target) altered when exercise-induced fatigue increased gradually.

Next, in **Chapter 5**, we performed a field study to examine to what extent anxiety and exercise-induced fatigue, in isolation and in combination, affected shooting and cognitive performance of soldiers. To that aim, soldiers performed a field track in a military practice village. Anxiety was manipulated by opponents that shot back at the participants with paint bullets, through time pressure, and through ego-stressor methods such as an audience and a video camera. Exercise-induced fatigue was induced by a 10-minute intense running exercise. Soldiers' shooting accuracy, decision making, and mathematical performance decreased significantly under anxiety. Whether exercise-induced fatigue was beneficial or detrimental to task performance depended on the task at hand. The increased arousal levels due to exercise prevented shooting accuracy from deteriorating in the decision task. In the decision task, participants had to distinguish hostile from friendly opponents and shoot at a target in case the opponent was hostile. In contrast, decision making suffered from the increased arousal. Participants more often failed to return fire when they were shot at by an opponent. Also, math performance tended to decrease. In sum, anxiety can negatively affect soldier performance, and exercise-induced fatigue may improve or deteriorate performance in combination with anxiety depending on the nature of the task.

Finally, in **Chapter 6**, we made a first step in validating the Capability-based Human-performance Architecture for Operational Simulation (CHAOS). This framework can simulate complex human behavior and is used to predict performance in circumstances that are hard to measure in practice, such as military missions. We implemented the data of **Chapter 2** in the CHAOS framework and investigated whether the model we built could reproduce the data.

Results showed that in the model anxiety affected task performance just as in the actual experiment. Moreover, the model results matched the empirical data very closely, which suggests that the resource based modeling approach in CHAOS has merit.

Conclusions

All three types of tasks relevant to operational performance that were investigated in the current thesis (cognitive, perceptual-motor, endurance) appear susceptible to anxiety. More precise, decrements were found in very attention demanding cognitive tasks, such as math (**Chapter 3 & 5)** and decision making (**Chapter 5**), as well as in far aiming tasks (dart throwing and rifle shooting, **Chapter 2, 3, & 5**), and even running, a task that is considered highly automated and thus requiring little attention, showed decreased efficiency due to anxiety (**Chapter 2**). Moreover, negative effects on performance generally seem to become larger when the attentional demands of the task increase. **Chapter 2** and **3** showed negative effects of anxiety to be larger when several tasks were performed concurrently, and for novices compared to experts. Whenever possible, people preferably seem to switch between tasks to cope with the increased attentional demands. When the secondary task was self-paced (counting backwards while dart throwing, **Chapter 3**) participants switched between tasks enabling them to maintain performance. In contrast, in **Chapter 2**, people threw darts while running on a treadmill. Consequently, they were not able to switch between tasks as then they would fall off the treadmill. Dart accuracy decreased in the combined running and dart-throwing condition.

With respect to exercise-induced fatigue, the current thesis suggests that the degree to which task performance is affected by acute bouts of exercise depends on the attentional demands of the task. Highly attentional demanding cognitive tasks seem more susceptible to negative effects of exercise-induced fatigue than perceptual-motor tasks. Cognitive tasks (e.g., shooting decisions) were (negatively) affected by exercise-induced fatigue (**Chapter 4 & 5**). However, **Chapter 4 and 5** indicate that shooting performance is rather resistant to exercise. Higher arousal levels due to exercise even prevented shooting accuracy from decreasing under anxiety, demonstrating that effects of anxiety and exercise-induced fatigue do not simply add up (**Chapter 5**). Results with fatigue are not as straightforward as with anxiety and further research is warranted. Recommendations for future research are provided later on in this epilogue.

Finally, simulation models, such as the CHAOS framework, can provide a valuable tool in simulating (and predicting) soldier performance under circumstances that are hard or even impossible to create in an experimental setting (**Chapter 6**). These simulation models may increase soldiers’ safety and increase their effectiveness under stressful and physically exerting circumstances.

Theoretical implications

Effects of anxiety

With respect to the mechanisms underlying the effects of anxiety on operational performance two types of theories were introduced in this thesis: distraction theories (e.g., Eysenck et al., 2007; Nieuwenhuys & Oudejans, 2012) and explicit-monitoring theories (e.g., Baumeister, 1984; Beilock & Carr, 2001; Lewis & Lindner, 1997). Overall, results presented in this thesis provide support for the central tenets of distraction theories. More precisely, the results seem to fit the three levels within the integrated model of Nieuwenhuys and Oudejans (2012) and provide some useful additions. Recapitulating, Nieuwenhuys and Oudejans suggested anxiety to influence goal-directed performance through: 1) threat-related attention, 2) threat-related interpretation, and 3) threat-related response tendencies (see Figure 7.1).

On an attentional level, anxiety is suggested to shift attention towards threat-related stimuli at the expense of attention directed at perceiving, selecting, and realizing possibilities for action. In line with this suggestion, results from **Chapter 2** show that anxiety can distract attention away from running and dart throwing and towards worries related to falling off the high scaffold. These worries and distracting thoughts were accompanied by decreased dart performance. Moreover, in **Chapter 3,** the assessment of visual attention through gaze behavior indicated shorter final fixations on the target (bulls eye) under anxiety. Shorter final fixations leave less time to perceive the information required for optimal task performance. Shorter final fixations predicted decreased dart throwing performance with anxiety. Most important, whereas previous studies generally focused on the duration of the final fixation, current results also stress the importance of the timing of the final fixation. When gaze deviates off the target too early, people are unable to pick up the information that is closest to dart release, which is the most up-to-date information.

On an interpretational level, anxiety is suggested to cause people to misinterpret information based on current feelings. In line with this suggestion, results of **Chapter 5** indicate that soldiers who were afraid to get shot were more prone to recognize an opponent directing a gun at them, even if the opponent actually surrendered.

On a behavioral response level, anxiety is proposed to lead to changes in amongst others action readiness. In line with this suggestion, people showed higher heart rates when they were anxious about falling off a high scaffold than near the ground (**Chapter 2**). Moreover, running became less efficient. This was shown by the less efficient stride pattern and higher oxygen uptake. These findings interestingly add to the current literature that anxiety affects endurance tasks next to cognitive and perceptual-motor tasks (**Chapter 2**).

Finally, in line with ACT, the current thesis provides support the idea that negative effects on performance generally seem to increase when the attentional load becomes larger. Besides anxiety, concurrent execution of cognitive, perceptual-motor, as well as endurance tasks contributes to the attentional load (**Chapter 2 & 3**). Moreover, for novices task execution is more attention demanding than for experts (**Chapter 3**). Together, the attentional demands of all of these factors seem to add up (**Chapter 2 & 3**).

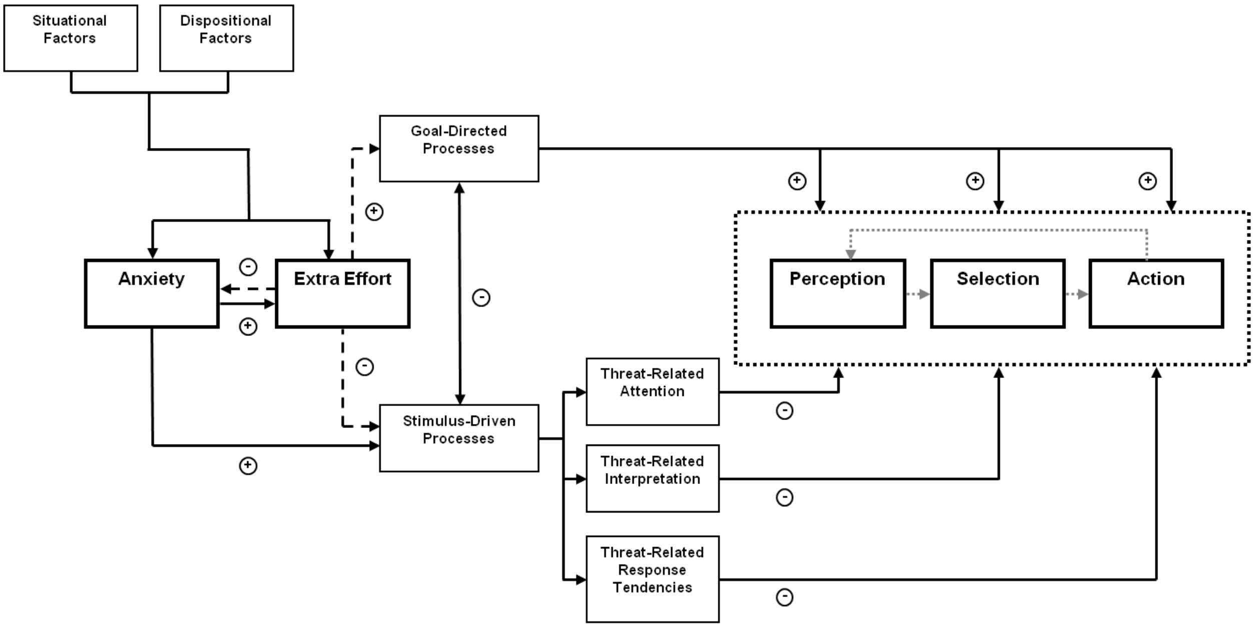

Figure 7.1. An integrated model of effects of anxiety on perceptual-motor performance (Nieuwenhuys & Oudejans, 2012).

Effects of exercise-induced fatigue

Many studies focused on the effects of exercise-induced fatigue on (cognitive and perceptual-motor) performance. However, empirical findings are still scattered and an overarching framework does not exist. Moreover, exercise-induced fatigue is a complex concept. As a result, different definitions and interpretations exist. Knicker et al. (2011) for example, reviewed symptoms of exercise-induced fatigue in sports competition, and they quantified exercise-induced fatigue using performance symptoms, such as technique execution and error rates. This approach assumes however, that if there is no degradation in performance, then there is no exercise-induced fatigue. This approach is clearly flawed; people can indeed experience exercise-induced fatigue without showing performance decrements (e.g., **Chapter 4;** McMorris et al., 1994, 1996, 1997, 1999). On the other hand, defining exercise-induced fatigue as a sole physiological process does not hold either. Following Noakes (2012), there is no doubt that motivation is necessary to achieve VO_2max. “For if exercise is regulated purely by physiological failure there is no need for any motivation to reach that inevitable state of biological failure; one simply continues to move the legs until they fail. Secondly, then there is no need for the symptoms of fatigue whose principal function must be to forestall homeostatic failure” (Noakes, 2012, p.4). Experiments in the current thesis support the view of exercise-induced fatigue as a combination of self-perceived (RPE) and physiological changes (e.g., heart rate, oxygen uptake).

With regard to the mechanisms that underlie the effects of exercise-induced fatigue on different types of performance, the inverted-U hypothesis is often proposed (Yerkes & Dodson, 1908). Davey (1973) was the first to present a theoretical explanation for a direct exercise-cognition interaction. He saw exercise as a stressor that would induce increases in arousal as exercise intensity increased, resulting in an inverted-U shaped relationship. However, the inverted-U hypothesis is merely a general prediction, not a theory that explains how, why, or precisely when arousal affects performance. Studies that provide an explanation for the effects of exercise on human behavior often suggest behavior to be affected through changes in attention (e.g., Arcelin, Delignières, & Brisswalter, 1998; Lambourne & Tomporowski, 2010; Noakes, 2012; Tomporowski, 2003). Interestingly, this line of thought is similar to that adopted in the large body of literature that already consists on the theoretical underpinnings of anxiety effects. Consequently, it would be interesting to investigate whether parallels can be drawn between the concepts of anxiety and exercise-induced fatigue. Although somewhat speculative, in the following section, we therefore discuss whether exercise-induced fatigue would fit into the integrated model of anxiety by Nieuwenhuys and Oudejans (2012). This might provide a first step towards building one model to explain combined effects of anxiety and exercise-induced fatigue. Therefore, findings on exercise-induced fatigue are discussed in the light of the integrated model of anxiety Nieuwenhuys and Oudejans (2012) (see Figure 7.1). Similarities and differences are highlighted. First, the suggestion that exercise-induced fatigue can affect human behavior on different levels (effects on attention, interpretation, and response tendencies) is addressed. Thereafter, we discuss whether central tenets of ACT are also in line with findings on exercise-induced fatigue, such as the suggestions that task efficiency is affected to a larger degree than task effectiveness, and that the investment of additional mental effort may compensate for negative performance effects.

Effects of exercise-induced fatigue on attention

It is important to distinguish between task execution *during* and *after* exercise. Just as with anxiety, inducing exercise-induced fatigue *during* task execution changes the performance setting from a single-task into a dual-task setting. Performing exercise consumes attention, even if it considers strongly automated movements such as walking or running (e.g., **Chapter 2**). Consequently, one would consider fewer resources to be available for cognitive performance. Indeed, cognitive performance appears to be negatively affected when performed during exercise (for a review, see Lambourne & Tomporowski, 2010). Moreover, reduced cognitive performance seems to be especially prominent for participants with relatively low fitness, providing another indication that exercise affects attentional capacity (Chang et al., 2012). Chang et al., (2012) argue that people with low fitness need to invest more attentional resources in conducting exercise. Consequently, they are also thought to have fewer resources available for cognitive performance. A viable explanation for these performance effects is provided by the hypofrontality hypothesis (Dietrich, 2003). The hypofrontality hypothesis states that the brain has a limited and constant metabolism and that performance of exercise and cognitive processing require similar neural structures and metabolic activity. Consequently, during exercise, available neural resources are drawn from cognitive processes towards the control and maintenance of motor movements in for example running.

On the other hand, when tasks are performed *after* exercise, a small positive overall effect on (cognitive) performance can be observed (Chang et al., 2012; Lambourne & Tomporowski, 2010). This positive effect is independent of exercise intensity. However, the duration of exercise might be particularly important. Performing tasks after exercise of relatively short duration appeared beneficial for performance (Chang et al., 2012). In line with Yerkes and

Dodson (1908), it can be argued that tasks were performed in an aroused state rather than a fatigued state, which might explain the positive effects on performance (Chang et al, 2012). Theoretically, cognition should be facilitated by the increase in brain concentrations of the neurotransmitters dopamine and norepinephrine that arises during and following moderate intensity exercise (catecholamines hypothesis, Cooper, 1973; McMorris et al., 2008). The few studies that reported decreases in performance after exercise, required their participants to exercise for at least 2 hours (Cian et al., 2000; Grego et al., 2004). Thus, only after prolonged exercise, exercise-induced fatigue seems to consume attention to the detriment of task performance.

Together, in line with findings on anxiety, results indicate that exercise can affect (cognitive) task performance through changes in attentional processes. Whether and to what extent these effects occur is dependent on the mode (during or prior to task execution) and duration of the exercise that is performed. Future research is warranted to further investigate how and to what extent exercise affects attentional capacity. Future research could for example investigate the effects of exercise-induced fatigue on dual-task performance. It is discussed that there are indications that the more demanding the task, the larger the performance effects. Moreover, findings are compatible with the view that attentional resources are limited (Eysenck et al., 2007). Thus, attentional resources seem to be consumed by both anxiety and exercise-induced fatigue. Moreover, just as anxiety, exercise-induced fatigue seems to be able to trigger stimulus-driven attention at the cost of goal-directed attention. Noakes (2012), for example, indicates that exercise-induced fatigue can distract attention away from task execution towards feelings of fatigue in marathon runners, thereby negatively affecting their performance outcome.

Exercise-induced fatigue-related interpretations

Similar to anxiety, exercise-induced fatigue has been found to change the way that people perceive their environment. Previous studies indicate that peoples' perceived action possibilities decrease when they are subjected to moderate or intense exercise (Bhalla & Proffitt, 1999; Pijpers et al., 2007; Proffitt et al., 1995). Pijpers et al. (2007), for example, instructed people to climb to exertion on a climbing wall and asked them to judge their maximum reaching distance at low and high levels of perceived exertion. Higher perceived exertion was associated with decreases in perceived maximum reaching distance. Similarly, inducing fatigue by having people complete an exhausting run resulted in people perceiving a hill to be steeper than when people were rested (Bhalla & Proffitt, 1999; Proffitt et al., 1995). Also, participants who wore a heavy backpack judged the hill to be steeper than their counterparts without a backpack (Bhalla & Proffitt, 1999).

On the other hand, **Chapter 5** shows an interesting difference between effects of anxiety and exercise-induced fatigue on shooting decisions. Soldiers interpreted the intended action of their opponent differently when they were anxious than when they were physically fatigued. In line with previous findings for police officers, anxiety caused soldiers to shoot too fast and consequently shoot more surrendering suspects (Nieuwenhuys et al., 2011). Nieuwenhuys et al. (2011) argued that people who are afraid to get shot are more prone to recognize an opponent's weapon even when there is none. In contrast, in **Chapter 5**, physically fatigued participants were too slow and more often failed to shoot when they were supposed to. Threat-related expectancies caused police officers to react even before visual information on the presence of a gun was available. Future research should elucidate what caused the soldiers in **Chapter 5** to fail to shoot. It would be interesting to conduct a follow-up study in which gaze behavior is assessed to investigate whether the soldiers look too late or too short to pick up crucial information. Or did they pick up the available information but were they too slow to react? In sum, in line with the integrated model of Nieuwenhuys and Oudejans (2012), exercise-induced fatigue, just as anxiety, seems to influence the way that we perceive our environment.

Exercise-induced fatigue induced behavioral changes

Obviously, exercise-induced fatigue induces physiological changes, such as increased heart rate and oxygen uptake. Anxiety-evoked physiological changes are suggested to reflect an increase in action readiness, thereby enabling an individual to quickly respond to a threat. In first instance, exercise-evoked physiological changes might also increase action readiness. Similar to anxiety, a warm-up period or a relatively short acute bout of exercise (as induced in **Chapter 5**) heightens one's state of physiological arousal, which might prepare soldiers to quickly respond to the upcoming tasks. Whether exercise-induced fatigue also evokes other behavioral responses, such as increased avoidance tendencies, remains to be determined.

Performance efficiency vs effectiveness and the investment of mental effort

Similar to anxiety, exercise-induced fatigue does not always negatively affect performance. Especially after exercise, various studies report maintained performance and even a small overall positive effect on cognitive performance (see reviews by Chang et al., 2012, Lambourne & Tomporowski, 2010). However, these reviews do not distinguish between task efficiency and effectiveness as suggested by Eysenck et al. (2007). Eysenck et al. (2007) proposed that the investment of more time or more mental effort to achieve the same performance indicates a decrease in task efficiency. Actually, cognitive performance is measured through response times in many of the studies that were included in several meta-analyses (e.g., Chang et al., 2012, Lambourne & Tomporowski, 2010). These response time tasks assessed the elapsed time between the detection of a sensory stimulus on a computer screen and a behavioral response (press the correct key) (Al-Yahya, Dawes, Smith, Dennis, Howells, & Cockburn, 2011). In general, during exercise, response times seem to increase, providing an indication of reduced efficiency (Lambourne & Tomporowski, 2010). Moreover, higher mental effort ratings at higher levels of exercise-induced fatigue have also been reported in previous studies (e.g., Eaves et al., 2008). People seem to try to compensate for possible negative effects of exercise-induced fatigue by investing extra effort.

On the other hand, after exercise, reductions in response time appear, which suggests that exercise can also disengage additional resources. In line with this suggestion, the current thesis shows that perceptual-motor performance (shooting accuracy) is not necessarily negatively affected by acute bouts of exercise, even at high intensity **(Chapter 4 and 5)**. In **Chapter 5**, the increased arousal level due to an acute bout of exercise even seems to protect shooting accuracy against the negative effects of anxiety. However, although shooting accuracy did not decrease in these studies, in **Chapter 4**, efficiency of task execution clearly suffered. People took more time to take the shot and invested more mental effort at higher levels of exercise-induced fatigue. The increase in invested mental effort indicates that, just as anxiety, exercise-induced fatigue can also serve a motivational function. Thus, just as with anxiety, people seem to become less efficient as exercise-induced fatigue increases, they invest more effort or need more time to perform the same task. These effects are most prominent when tasks are performed during exercise.

In sum, the majority of findings on effects of exercise(-induced fatigue) are compatible with the integrated model of the effects of anxiety on performance by Nieuwenhuys and Oudejans (2012). Exercise(-induced fatigue) can affect attention and interpretation, and can induce behavioral changes. Moreover, people compensate for the negative effects of exercise(-induced fatigue) on performance by investing more mental effort and/or time. However, task performance during exercise should be distinguished from task performance after exercise. When tasks are performed *during* exercise, exercise(-induced fatigue), just as anxiety, changes a single-task into a dual-task situation and competes with the task at hand for limited attentional resources. Cognitive tasks in an operational context (e.g., communicating coordinates, decision making, vigilance) often have to be performed during walking or running over heavy terrain. On the other hand, *after* exercise, the task is generally performed in an ‘aroused’ state which is mostly beneficial to performance and is particularly important for perceptual-motor tasks such as shooting that are generally performed after exercise.

Practical implications

Performing under threatening and physically exerting circumstances is inherent to soldier performance. Recent research in the International Security Assistance Force for Afghanistan (2009-2010) on Dutch soldiers for example stresses the unpredictable character of modern military operations and the consequent variety of stress burdens that soldiers carry (Boermans, Kamphuis, Delahaij, Korteling, & Euwema, 2013). Moreover, soldiers are confronted with situations in which they have to carry heavy loads or cross heavy terrain. The current thesis demonstrates that these stressors can negatively affect performance on tasks and combinations of tasks that are important in soldier practice.

In **Chapter 2-4**, anxiety has been shown to negatively affect shooting accuracy, shooting decisions, and to cause less efficient running through less efficient gait patterns and higher energy expenditure. Effects are suggested to be larger when the attentional demands become larger, for example through dual-tasking. In military practice, soldiers have to monitor the ground for obstacles and safe locations for foot placement while simultaneously communicating with members of their squad, scan the environment for the enemy, and attending to information from communication networks (Mahoney et al., 2007). Moreover, in these settings, aiming tasks are often combined with cognitive tasks, such as strategic decision making. Furthermore, the current thesis suggests that soldiers benefit from the highest possible skill level. Negative effects of anxiety were larger for participants that were novices in far aiming than for experts. For novices, dual tasking appeared more effortful, and far aiming accuracy was more susceptible to anxiety. Novices need to allocate more attention to task execution. Consequently, a high skill level would leave soldiers with more attention available to cope with anxiety or dual tasking.

In addition to anxiety, the current thesis suggests that exercise-induced fatigue can also alter shooting decisions. More precise, the distance from which people decide to shoot is suggested to increase at high levels of physical exertion. As a possible consequence, soldiers might decide to shoot from too far away to get a clear shot, thereby increasing the risk of missing the target and consequently increasing the risk of unintended casualties.

Although the findings described above highlight some interesting points of interest for military practice, they did not measure soldiers. As such, results do not automatically generalize to soldier performance and more research is warranted to verify these findings for soldier practice. The experiments in **Chapter 2-4** were designed to further our understanding of separate and combined effects of anxiety and exercise-induced fatigue on tasks that are important to operational performance. **Chapter 5** meets the demand for test circumstances that are more representative of the real world (e.g., Dicks et al., 2010; Mann et al., 2010; Nieuwenhuys et al., 2012). The most important practical implications are therefore provided by the field study in **Chapter 5**. Results of this chapter indicate that infantry soldiers shoot less accurately under anxiety. Although soldiers are expected to perform well under heightened levels of anxiety, results indicate that shooting accuracy decreased with 20-40% which is comparable to police officers (drop around 32%, Nieuwenhuys & Oudejans, 2010; around 16%, Nieuwenhuys & Oudejans, 2011; around 22%, Oudejans, 2008).

Moreover, following **Chapter 5**, soldiers are suggested to make more errors in decision making and in math performance in threatening situations. The latter is suggested to have serious consequences for tasks that include fast calculations, such as communicating coordinates or counting rifle magazines. Effects of exercise-induced fatigue on soldier performance appear more complex and seems to depend on exercise duration, mode (task performance during or after exercise), and the attentional demands of the task. However, moderate arousal levels induced through exercise are suggested to negatively affect soldiers' shooting decisions, but be beneficial for their shooting accuracy.

All in all, the current thesis indicates that the debilitative effects of anxiety and exercise-induced fatigue on operational performance should not be overlooked. Moreover, the current thesis supports the notion that theories and methods from sport psychology might be applied successfully to the domain of human factors (e.g., Eccles et al., 2011). Finally, future research is suggested to continue the development of computer simulations that might allow us to predict human performance under circumstances that are hard or sometimes even impossible to create in an experimental setting. Accurate predictions of soldier performance on the battlefield may help to prevent casualties in the future.

8

Dutch summary

Effecten van angst en fysieke vermoeidheid op operationeel presteren

In dit proefschrift heb ik mij ten doel gesteld inzicht te verwerven in de afzonderlijke en gecombineerde effecten van angst en fysieke inspanning op operationeel presteren. De afzonderlijke effecten van deze factoren zijn eerder onderzocht in de sport en het functioneren van politie-ambtenaren. Ondanks dat deze stressoren in de praktijk vaak samen voorkomen en het niet goed ermee om kunnen gaan ernstige gevolgen kan hebben, is er nog weinig onderzoek gedaan naar de gecombineerde effecten van angst en fysieke vermoeidheid. Er is ook weinig bekend over de manier waarop deze stressoren de uitvoering van bepaalde taken beïnvloeden die in het operationele domein belangrijk zijn. Te denken valt aan taken waarin het uithoudingsvermogen centraal staat, zoals rennen.

In dit proefschrift heb ik getracht de volgende vragen te beantwoorden:
In **Hoofdstuk 2:** Wat is de invloed van angst op taken waarin het uithoudingsvermogen centraal staat, zoals rennen (al dan niet uitgevoerd in combinatie met een dubbeltaak)? In **Hoofdstuk 3**: Hoe wordt de prestatie op miktaken beïnvloed door angst, een cognitieve dubbeltaak en expertise? In **Hoofdstuk 4**: Wat is de invloed van geleidelijk toenemende fysieke vermoeidheid op schietgedrag in een achtervolgingstaak? In **Hoofdstuk 5**: Wat zijn de afzonderlijke en gecombineerde effecten van angst en fysieke inspanning op de schietprestatie en op de cognitieve prestatie van militairen?
In **Hoofdstuk 6**: Kunnen de resultaten van deze experimenten worden gebruikt om een simulatiemodel te bouwen dat soldaatgedrag kan voorspellen tijdens militaire missies? Het antwoord op deze vragen wordt beschreven in de samenvatting hieronder.

Samenvatting

Het is bekend dat angst een negatief effect kan hebben op cognitieve taken (zoals het nemen van beslissingen) en miktaken (zoals schieten en werpen, e.g., Eysenck et al., 2007, Wilson, 2008; Nieuwenhuys & Oudejans, 2012). Echter, of en hoe angst overwegend aerobe taken, zoals rennen, beïnvloedt was onbekend.

In **Hoofdstuk 2** werd de invloed van angst op rennen onderzocht en werd de invloed van angst op de combinatie van rennen en een miktaak onderzocht. Proefpersonen renden 10 minuten op een loopband. Gedurende de laatste 2 minuten werd het rennen gecombineerd met een darttaak. In de lage-angst conditie werd de loopband op de grond vastgezet. In de hoge-angst conditie stond de loopband op een 4,2 meter hoge steiger. Na afloop van beide angstcondities werd de proefpersonen gevraagd om aan te geven waar ze hun aandacht op hadden gericht tijdens het rennen. Uit de resultaten bleek dat proefpersonen inderdaad meer angst ervoeren in de hoge-angst conditie dan in de lage-angst conditie. Daarnaast hadden de proefpersonen in de hoge-angst conditie meer afleidende gedachten en zorgen, onder andere over de kans op vallen. Ook zorgde angst voor een minder efficiënt looppatroon: Men nam meer en kleinere schreden. Er werd een langere contacttijd van de voet met de grond vastgesteld en er werd een hogere zuurstofopname gemeten. Tot slot werd ook de darttaak minder precies uitgevoerd in de hoge-angst conditie. De hoogste waarden voor alle kinematische en metabole variabelen werden gevonden in de conditie waarin rennen, darten en angst werden gecombineerd (behalve voor schredelengte, daar waren het de kleinste waarden. Deze bevindingen laten zien dat angst ook taken waarin het uithoudingsvermogen centraal staat, zoals rennen, negatief kan beïnvloeden. Rennen, mikken en angst lijken alle drie te concurreren om aandacht. Dit leidt tot een cumulatief effect op de gemeten parameters en tot een suboptimale prestatie wanneer de verschillende factoren gecombineerd worden.

In **Hoofdstuk 3** werd het effect van de triade 'angst - een cognitieve dubbeltaak - expertise' op een miktaak onderzocht. Alle drie deze factoren werden verondersteld aandacht te consumeren. Darters (leken en experts) voerden een darttaak uit laag op een klimmuur (lage-angst conditie) en hoog (hoge-angst conditie) op een klimmuur en met en zonder een cognitieve dubbeltaak (terugteltaak). Het kijkgedrag van de proefpersonen werd gemeten als maat van de geïnvesteerde (visuele) aandacht. Angst veroorzaakte een afname in dartprestatie, maar alleen voor de leken. De terugteltaak (dubbeltaak) had geen invloed op de dartprestaties, waarschijnlijk omdat proefpersonen er de voorkeur aan gaven om de darttaak en de terugteltaak af te wisselen in plaats van ze tegelijkertijd uit te voeren. Analyse van het kijkgedrag liet zien dat afnamen in prestatie vergezeld gingen van veranderingen in het kijkgedrag. De laatste fixatie op het doel (bulls eye) was korter en proefpersonen keken eerder weg van het doel. Deze bevindingen benadrukken hoe belangrijk het voor een succesvolle taakuitvoering is om lang genoeg naar het doel te kijken dat je wilt raken en om zo laat mogelijk de (visuele) informatie op te pikken die nodig is voor de taakuitvoering. De bevinding dat angst alleen voor de leken tot een afname in de prestatie leidde en dat de dubbeltaak voor leken meer mentale inspanning kostte, laat zien dat angst, expertise en de dubbeltaak alle drie van invloed waren op het vermogen aandacht te besteden. Dit suggereert dat ons vermogen aandacht te besteden niet onbegrensd is en dat de efficiëntie en effectiviteit waarmee we taken uitvoeren afneemt wanneer deze grenzen worden overschreden.

In **Hoofdstuk 4** werden de effecten van geleidelijk toenemende fysieke vermoeidheid op schietgedrag onderzocht in een 'pursue-and-shoot' taak. Proefpersonen renden op een loopband en achtervolgden een doel in een virtuele omgeving. Ze mochten de loopband stoppen om vervolgens een schot op het doel af te vuren wanneer ze dat wilden. Gedurende de 20-minuten durende achtervolgingstaak nam de fysieke vermoeidheid geleidelijk toe. Analyse van de data liet zien dat de schietprestatie niet veranderde met toenemende vermoeidheid. De afstand tot het doel waarop proefpersonen besloten te schieten liet een U-vormige relatie zien met fysieke vermoeidheid. Het laagste punt op de U-vormige curve, ofwel de kleinste afstand tot het doel, werd bereikt bij een score op de Borgschaal van 6.5. Zoals verwacht stopten proefpersonen eerder met rennen, richtten ze hun wapen langer op het doel en schoten ze minder vaak naarmate ze meer fysiek vermoeid raakten. Deze bevindingen laten zien dat fysiologische parameters de overgang tussen verschillende acties kunnen beïnvloeden. Oftewel, de beslissing om te schieten (afstand tot het doel) veranderde naarmate de fysieke vermoeidheid toenam.

Vervolgens heb ik in **Hoofdstuk 5** een veldstudie uitgevoerd om te onderzoeken in welke mate angst en fysieke vermoeidheid, onafhankelijk van elkaar en in combinatie met elkaar, de schietprestatie en cognitieve prestatie van militairen beïnvloeden. Daartoe hebben soldaten een parcours afgelegd in en rondom een oefenhuis in een militair oefendorp. Angst werd gemanipuleerd (a) met behulp van opponenten die terugschoten met verfkogels, (b) door tijdsdruk en (c) door ego-stressor methoden zoals publiek en een videocamera. De proefpersonen werden fysiek vermoeid door ze 10 minuten te laten rennen. Schietnauwkeurigheid, besluitvorming en rekenprestaties bleken significant slechter in de hoge-angst conditie. Wat betreft fysieke vermoeidheid was het afhankelijk van de taak of er een positief of negatief effect op prestatie werd gevonden. Militairen die zich fysiek hadden ingespannen wisten hun schietprestaties in de beslissingstaak in stand te houden in de hoge-angst conditie terwijl deze bij de niet-vermoeide militairen achteruit ging. In de beslissingstaak verscheen er een opponent die op ze schoot of zich overgaf. In het eerste geval moesten ze schieten, in het tweede geval niet. De besluitvorming ging wel achteruit na fysieke inspanning. Proefpersonen lieten vaker na om te schieten in het geval dat ze werden beschoten door een opponent. De rekenprestaties namen bovendien af. Kortom, angst kan de prestatie van militairen negatief beïnvloeden en wanneer fysieke vermoeidheid en angst samen voorkomen, is het afhankelijk van het type taak dat wordt uitgevoerd of dit een positief danwel een negatief effect op de prestatie heeft.

Tenslotte heb ik in **Hoofdstuk 6** een eerste stap gemaakt in het valideren van de Capability-based Human-performance Architecture for Operational Simulation (CHAOS). Dit raamwerk wordt gebruikt om complex menselijk gedrag te simuleren. Er is een model gebouwd op basis van de helft van de data uit **Hoofdstuk 2**. Vervolgens heb ik onderzocht of het model de andere helft van de empirische dataset kon reproduceren. De resultaten uit het model bleken overeen te komen met de empirische resultaten. Bovendien bleek het model de dartprestatie op eenzelfde manier te beïnvloeden als in het daadwerkelijke experiment. Dit laat zien dat de op resources gebaseerde modeleringsaanpak in CHAOS een waardevol hulpmiddel kan zijn om soldaatgedrag te voorspellen in situaties waarin in de praktijk moeilijk metingen te verrichten zijn, zoals tijdens militaire missies.

Conclusies

In dit proefschrift werden drie type taken onderzocht die van belang zijn in het operationele domein: cognitieve taken, perceptueel-motorische taken en taken waarin het uithoudingsvermogen centraal staat. Alle drie bleken vatbaar te zijn voor (de effecten van) angst. Een afname in prestatie werd gevonden voor erg aandachtvragende cognitieve taken, zoals rekentaken (**Hoofdstuk 3 & 5**) en besluitvorming (**Hoofdstuk 5**), maar ook in verre miktaken (darten en schieten, **Hoofdstuk 2, 3 & 5**), en zelfs rennen, een taak die als zeer geautomatiseerd beschouwd wordt en waarvan verwacht werd dat er weinig aandacht voor nodig is, werd minder efficiënt onder invloed van angst (**Hoofdstuk 2**). De negatieve effecten op prestatie lijken groter te worden naarmate de aandachtseis die de taak stelt toeneemt. In **Hoofdstuk 2 en 3** werden grotere negatieve effecten van angst gevonden wanneer er meerdere taken tegelijk werden uitgevoerd en tevens waren de effecten groter voor leken dan voor experts. **Hoofdstuk 3** laat bovendien zien dat mensen, wanneer ze de kans krijgen, bij voorkeur afwisselen tussen taken en op deze manier met de toegenomen aandachtseisen om gaan. Wanneer de dubbeltaak in een zelfgekozen ritme mocht worden uitgevoerd (terugtellen tijdens het darten in **Hoofdstuk 3**) wisselden de proefpersonen de twee taken af. Dit stelde ze in staat om hun prestatie in stand te houden. In **Hoofdstuk 2** daarentegen voerden de proefpersonen een darttaak uit terwijl ze renden op een loopband. Aangezien ze de loopband niet konden stoppen, was het niet mogelijk de twee taken af te wisselen. Als gevolg nam de dartprestatie af in de conditie waarin rennen en darten werden gecombineerd.

Wat betreft fysieke vermoeidheid laat dit proefschrift zien dat de mate waarin de prestatie op een taak wordt beïnvloed door fysieke inspanning afhangt van de aandachtseisen van de taak.

Cognitieve taken vereisen veel aandacht en lijken vatbaarder voor de negatieve effecten van fysieke vermoeidheid dan perceptueel-motorische taken. Fysieke vermoeidheid had een (negatief) effect op cognitieve taken (bv. schietbeslissingen) in **Hoofdstuk 4 en 5**, maar in deze hoofdstukken bleef de schietprestatie onaangetast. Fysieke inspanning weerhield de schietnauwkeurigheid er zelfs van achteruit te gaan onder angst (**Hoofdstuk 5**). Dit laat zien dat de effecten van angst en fysieke vermoeidheid niet eenvoudigweg bij elkaar opgeteld kunnen worden. De effecten van fysieke vermoeidheid op prestatie zijn niet zo onomwonden als de effecten van angst en vervolgonderzoek is dus nodig.

Tot slot laat het onderzoek in dit proefschrift zien dat simulatiemodellen, zoals die in het CHAOS raamwerk een waardevol hulpmiddel kunnen zijn voor het simuleren (en voorspellen) van soldaatgedrag onder omstandigheden die moeilijk, of zelfs onmogelijk, in een experimentele setting na te bootsen zijn (**Hoofdstuk 6**). Deze simulatiemodellen kunnen een bijdrage leveren aan de veiligheid van soldaten en kunnen de effectiviteit van missies onder stressvolle en fysiek uitputtende omstandigheden helpen vergroten.

9

References

References

Abernethy, B., Hanna, A., & Plooy, A. (2002). The attentional demands of preferred and non-preferred gait patterns. *Gait and Posture, 15,* 256–265.

Acevedo, E., Dzewaltowski, D. A., Kubitz, K. A., & Kraemer, R. R. (1999). Effects of a proposed challenge on effort sense and cardiorespiratory responses during exercise. *Medicine and Science in Sports and Exercise, 31,* 1460–1476.

Al-Yahya, E., Dawes, H., Smith, L., Dennis, A., Howells, K., & Cockburn, J. (2011). Cognitive motor interference while walking: a systematic review and meta-analysis. *Neuroscience & Biobehavioral Reviews, 35*, 715-728.

Arcelin, R., Delignières, D., & Brisswalter, J. (1998). Effects of physical exercise on choice reaction processes. *Perceptual and Motor Skills, 87*, 175-185.

Aune, T.K., Ingvaldsen, R.P., & Ettema, G.J.C. (2008). Effects of physical fatigue on motor control at different skills levels. *Perceptual & Motor Skills, 106,* 371-386.

Bainbridge, F. A. (1931). The physiology of muscular exercise, 3rd Edn. London: Longman, Green and Co.

Bakker, F. C., Vanden Auweele, Y., & Van Mele, V. (2003). Handleiding bij de Competitie-Belevings-Vragenlijst (CBV) en Vragenlijst Beleving voor een sportwedstrijd (VBS). In Manual for the Dutch version of the Sport Competition Anxiety Test (SCAT) and the Dutch version of the Competitive State Anxiety Inventory-2 (CSAI-2). Leuven: Belgium: Acco.

Banks, S. B., Stytz, M. R. (2003). Progress and prospects for the development of computer-generated actors for military simulation: Part 2 – Reasoning system architectures and human performance modeling. *Presence, 12,* 422-436.

Barak, Y., Wagenaar, R. C., & Holt, K. G. (2006). Gait characteristics of elderly people with a history of falls: A dynamic approach. *Physical Therapy, 86,* 1501–1510.

Barr, D., Gregson, W., & Reilly, T. (2010). The thermal ergonomics of firefighting reviewed. *Applied Ergonomics, 41*, 161-172.

Barton, G. J., Vanrenterghem, J., Lees, A., & Lake, M. (2006). A method for manipulating a movable platform’s axes of rotation: A novel use of the CAREN system. *Gait and Posture, 24,* 510–514.

Bassett, D. R. Jr. & Howley, E. T. (1997). Maximal oxygen uptake: “Classical” versus “contemporary” viewpoints. *Medicine and Science in Sports and Exercise, 29,* 591-603.

Bassett, D. R. Jr. & Howley, E. T. (2000). Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Medicine and Science in Sports and Exercise, 32,* 70-84.

Baumeister, R.F. (1984). Choking under pressure: Self-consciousness and paradoxical effects of incentives on skillful performance. *Journal of Personality and Social Psychology, 46,* 610-620.

Behan, M., & Wilson, M. (2008). State anxiety and visual attention: the role of the quiet eye period in aiming to a far target. *Journal of Sports Sciences, 26,* 207-215. doi:10.1080/02640410701446919.

Beilock, S. L., Bertenthal, B. I., Hoerger, M. & Carr, T. H. (2008). When does haste make waste? Speed-accuracy tradeoff, skill level, and the tools of the trade. *Journal of Experimental Psychology: Applied, 14*, 340-352.

Beilock, S.L. & Carr, T.H. (2001). On the fragility of skilled performance: what governs choking under pressure? *Journal of Experimental Psychology: General, 130,* 701-725.

Beilock, S. L., Kulp, C. A., Holt, L. E., & Carr, T. H. (2004). More on the fragility of performance: Choking under pressure in mathematical problem solving. *Journal of Experimental Psychology: General, 133,* 584-600.

Beuter, A., & Duda, J. L. (1985). Analysis of the arousal/motor performance relationship in children using movement kinematics. Journal of Sport Psychology, 7, 229–243.

Bhalla, M. & Proffitt, D. R. (1999). Visual-motor recalibration in geographical slant perception. *Journal of Experimental Psychology: Human Perception & Performance 25,* 1076–1096.

Blacker, S. D., Carter, J. M., Wilkinson, D. M., Richmond, V. L., Rayson, M. P., & Peattie. M. (2013). Physiological responses of police officers during job simulations wearing chemical biological, radiological, and nuclear personal protective equipment. *Ergonomics, 56,* 137–147.

Boermans, S., Kamphuis, W., Delahaij, R., Korteling, J., Euwema, M. (2013). Perceived demands during modern military operations. *Military Medicine, 7,* 722-728.

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise, 14,* 377–381.

Brown, T. L., & Carr, T. H. (1989). Automaticity in skill acquisition: mechanisms for reducing interference in concurrent performance. *Journal of Experimental Psychology, 15,* 686-700.

Brown, L. A., Doan, J. B., McKenzie, N. C., & Cooper, S. A. (2006). Anxiety-mediated gait adaptations reduce errors of obstacle negotiation among younger and older adults: Implications for fall risk. *Gait and Posture, 24,* 418–423.

Caird, S. J., McKenzie, A. D., & Sleivert, G. G. (1999). Biofeedback and relaxation techniques improve running economy in sub-elite long distance runners. *Medicine and Science in Sports and Exercise, 31,* 717–722.

Carillo, A. E., Christodoulou, V. X., Koutedakis, Y., & Flouris, A. D. (2011). Autonomic nervous system modulation during an archery competition in novice and experienced adolescent archers. *Journal of Sports Sciences, 29,* 913–917.

Causer, J., Bennett, S. J., Holmes, P. S., Janelle, C. M., & Williams, A. M. (2010). Quiet eye duration and gun motion in elite shotgun shooting. *Medicine and Science in Sports and Exercise, 42,* 1599-1608. doi:10.1249/MSS.0b013e3181d1b059.

Causer, J., Holmes, P. S., Smith, N. C., & Williams, A. M. (2011). Anxiety, movement kinematics, and visual attention in elite-level performers. *Emotion, 11,* 595–602. doi:10.1037/a0023225.

Cavanagh, P. R., & Williams, K. R. (1982). The effect of stride length variation on oxygen uptake during distance running. *Medicine and Science in Sports and Exercise, 14,* 30–35.

Chang, Y. K., Labban, J. D., Gapin, J. I., & Etnier, J. L. (2012). The effects of acute exercise on cognitive performance: A meta-analysis. *Brain Research, 1453,* 87-101.

Cian, C., Koulmann, N., Barraud, P. A., Raphel, C., Jimenez, C., & Melin, B. (2000). Influences of variations in body hydration on cognitive function: effects of hyperhydration, heat stress, and exercise-induced dehydration. *Journal of Psychophysiology, 14,* 29-36.

Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Cooper, C. J. (1973). Anatomical and physiological mechanisms of arousal with specific reference to the effects of exercise. *Ergonomics, 16,* 601-609.

Corbetta, M., Patel, G., & Shulman, G. L. (2008). The reorienting system of the human brain: from environment to theory of mind. *Neuron, 58,* 306-324. doi:10.1016/ j.neuron.2008.04.017.

Corbetta, M., & Shulman, G. L. (2002).Control of goal-directed and stimulus-driven attention in the brain. *Neuroscience, 3,* 201–215. doi:10.1038/nrn755.

Dallam, G. M., Wilber, R. L., Jadelis, K., Fletcher, G., & Romanov, N. (2005). Effect of a global alteration of running technique on kinematics and economy. *Journal of Sports Sciences, 23,* 757–764.

Daniels, J. T. (1985). A physiologist's view of running economy. *Medicine and Science in Sports and Exercise, 17,* 332–338.

Darke, S. (1988). Anxiety and working memory capacity. *Cognition and Emotion, 2,* 145-154.

Davey, P.R., Thorpe, R.D., & Williams, C. (2002). Fatigue decreases skilled tennis performance. *Journal of Sports Sciences, 20,* 311-318.

Dekay, M. L., Patiño-Echeverri, D., & Fischbeck, P. S. (2009). Better safe than sorry: Precautionary reasoning and implied dominance in risky decisions. *Journal of Behavioral Decision Making, 22,* 338–361.

De Oliveira, R. F., Oudejans, R. R. D., & Beek, P. J. (2006). Late information pick-up is preferred in basketball jump shooting. *Journal of Sports Sciences, 24,* 933-940. doi:10.1080/02640410500357101.

Dicks, M., Button, C., & Davids, K. (2010). Examination of gaze behaviors under in situ and video simulation task constraints reveals differences in information pickup for perception and action. *Attention, Perception, & Psychophysics, 72,* 706-720.

Dietrich, A. (2003). Functional neuroanatomy of altered states of consciousness: the transient hypofrontality hypothesis. *Conscious Cognition, 12,* 231–256.

Dubik, J. (2003). Effects-based decisions and action. *Military Review, 8,* 33-36.

Eaves, D. L., Hodges, N. J., & Williams, A. M. (2008). Energetic costs of incidental visual coupling during treadmill running. *Medicine and Science in Sports and Exercise, 40,* 1506–1514.

Eccles, D. W., Ward, P., Woodman, T., Janelle, C. M., Le Scanff, C., Ehrlinger, J., Castanier, C., & Coombes, S. A. (2011). Where's the emotion? How sport psychology can inform research on emotion in human factors. *Human Factors, 53,* 180-202.

Evans, R., Scoville, C., Ito, M. A., & Mello, R. P. (2003). Upper body fatiguing exercise and shooting performance. *Military Medicine, 168,* 451–456.

Ebersbach, G., Dimitrijevic, M. R., & Poewe, W. (1995). Influence of concurrent tasks on gait: A dual task approach. *Perceptual and Motor Skills, 81,* 107–113.

Eysenck, M. W., & Calvo, M. G. (1992). Anxiety and performance: The processing efficiency theory. *Cognition and Emotion, 6,* 409–434.

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion, 7,* 336–353. Doi: 10.1037/1528-3542.7.2.336.

Eysenck, M. W., Payne, S., & Derakshan, N. (2005). Trait anxiety, visuospatial processing, and working memory. *Cognition and Emotion, 19,* 12140-1228. http://dx. doi.org/10.1080/02699930500260245.

Féry, Y. A., Ferry, A., Vom Hofe, A., & Rieu, M. (1997). Effect of physical exhaustion on cognitive functioning. *Perceptual and Motor Skills, 84,* 291-298.

Freud, S. (1936).The problem of anxiety. New York: W.W. Norton

Frijda, N. H. (1986). The emotions. New York: Cambridge University Press.

Fung, J., Richards, C. L., Malouin, F., McFadyen, B. J., & Lamontagne, A. (2006). A treadmill and motion coupled virtual reality system for gait training post-stroke. *Cyberpsychology and Behavior, 9,* 157–162.

Gibson, J. J. [1979] (1986). The ecological approach to visual perception. Hillsdale, NJ: Erlbaum.

Glenn, F. A., & Stokes, J. M. (2005). Validation in a virtual world: a challenge for cognitive models in SBA. The 2005 Behavior Representation in Modeling and Simulation (BRIMS) Conference.

Gonzales, A. J., & Murillo, M. (1999). Validation of human behavior models. The 1999 Spring Simulation Interoperability Workshop, 50-57.

Goonetilleke, R. S., Hoffmann, E. R., & Lau, W. C. (2009). Pistol shooting accuracy as dependent on experience, eyes being opened and available viewing time. *Applied Ergonomics, 40,* 500–508.

Gray, R. (2004). Attending to the execution of a complex sensorimotor skill: Expertise differences, choking, and slumps. *Journal of Experimental Psychology: Applied, 10,* 42-54.

Grebot, C., Groslambert, A., Pernin, J., Burtheret, A., & Rouillon, J. (2003). Effects of exercise on perceptual estimation and short-term recall of shooting performance in biathlon. *Perceptual and Motor Skills, 97,* 1107-1114.

Grego, F., Vallier, J. M., Collardeau, M., Bermon, S., Ferrari, P., Candito, M., Bayer, M., & Brisswalter, J. B. (2004). Effects of long duration exercise on cognitive function, blood glucose, and counter-regulatory hormones in male cyclists. *Neuroscience Letters, 362,* 76-80.

Groslambert, A., Candau, R., Hoffman, M. D., Bardy, B., & Rouillon, J. D. (1999). Validation of simple tests of biathlon shooting ability. *International Journal of Sports Medicine, 20,* 179–182.

Gucciardi, D. F. & Dimmock, J. A. (2008). Choking under pressure in sensorimotor skills: conscious processing or depleted attentional resources? *Psychology of Sport and Exercise, 9,* 45-59.

Hancock, P. A. & Szalma, J. (2008). Performance Under Stress. Aldershote: Ashgate.

Hancock, P. A. & Warm, J. (1989). A dynamic model of stress and sustained attention. *Human Factors, 31,* 519-537.

Haslam, D. R. (2007). Sleep loss, recovery sleep, and military performance. *Ergonomics, 25,* 163-178.

Hatfield, B. D., & Hillman, C. H. (2001). The psychophysiology of sport: A mechanistic understanding of the psychology of superior performance. In R. N. Singer, C. H. Hausenblas, & C. M. Janelle (Eds.), *Handbook of sport psychology* (2nd ed. pp. 362–386). New York: Wiley.

Hausdorff, J. M., Yogev, G., Springer, S., Simon, E. S., & Giladi, N. (2005). Walking is more like catching than tapping: Gait in the elderly as a complex cognitive task. *Experimental Brain Research, 164,* 541–548.

Hockey, G. R. J. & Hamilton, P. (1983). The cognitive patterning of stress states. In G. R. J. Hockey (Ed.), *Stress and fatigue in human performance*. Chichester: Wiley.

Hoffman, M. D., Gilson, P. M., Westenburg, T. M. & Spencer, W. A. (1992). Biathlon shooting performance after exercise of different intensities. *International Journal of Sports Medicine, 13,* 270-273.

Horrey, W. J., & Simons, D. J. (2007). Examining cognitive interference and adaptive safety behaviors in tactical vehicle control. *Ergonomics, 50,* 1340–1350.

Houtman, I. L., & Bakker, F. C. (1989). The anxiety thermometer: A validation study. *Journal of Personality Assessment, 53,* 575–582.

Humphreys, M.S. & Revelle, W. (1984). Personality, motivation, and performance: A theory of the relationship between individual differences and information processing. *Psychological Review, 91,* 153-184.

Ito, M. A., Sharp, M. A., Johnson, R. F., Merullo, D. J., & Mello, R. O. (1999). Rifle shooting accuracy during recovery from fatiguing exercise. In *Proceedings of the 22nd Army Science Conference, Baltimore, MD, December* 11–13.

Jackson, R. C., Ashford, K. J., & Norsworthy, G. (2006). Attentional focus, dispositional reinvestment, and skilled motor performance under pressure. *Journal of Sport & Exercise Psychology, 28,* 49-68.

Janelle, C.M. (2002). Anxiety, arousal and visual attention: A mechanistic account of performance variability. *Journal of Sports Sciences, 20,* 237-251.

Janelle, C.M., & Hatfield, B. D. (2008). Visual attention and brain processes that underlie expert performance: Implications for sport and military psychology. *Military Psychology, 20,* S39–S69.

Janelle, C. M., Hillman, C. H., Apparies, R., Murray, N. P., Meili, L., Fallon, E. A., et al. (2000). Expertise differences in cortical activation and gaze behavior during rifle shooting. *Journal of Sport & Exercise Psychology, 22,* 167-182.

Jones, A. M., & Doust, J. H. (1996). A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. *Journal of Sport Sciences, 14,* 321–327.

Kahneman, D. (1973). Attention and effort. Prentice-Hall, Englewood Cliffs, NJ.

Knicker, A. J., Renshaw, I., Oldham, R. H. & Cairns, S. P. (2011). Interactive processes link the multiple symptoms of fatigue in sport competition. *Sports Medicine, 41,* 307-328.

Koedijker, J. M., Oudejans, R. R. D., & Beek, P. J. (2007). Explicit rules and direction of attention in learning and performing the table tennis forehand. *International Journal of Sport Psychology, 38,* 227-244.

Koedijker, J. M., Oudejans, R. R. D., & Beek, P. J. (2008). Table tennis performance following explicit and analogy learning over 10000 repetitions. *International Journal of Sport Psychology, 39,* 237-256.

Kushleyeva, Y., Salvucci, D. D., & Lee, F. J. (2005). Deciding when to switch tasks in time-critical multitasking. *Cognitive Systems Research, 6,* 41-49.

Lakie, M. (2010). The influence of muscle tremor on shooting performance. *Experimental Physiology, 95,* 441–450.

Lam, W. K., Maxwell, J. P., & Masters, R. (2009). Analogy learning and the performance of motor skills under pressure. *Journal of Sport & Exercise Psychology, 31*, 337-357.

Lambourne, K. & Tomporowski, P. (2010). The effect of exercise-induced arousal on cognitive task performance: A meta-regression analysis. *Brain Research, 1341*, 12-24.

Leech, J., Gresty, M., Hess, K., & Rudge, P. (1977). Gaze failure, drifting eye movements, and centripetal nystagmus in cerebral disease. *British Journal of Ophthalmology, 61*, 774-781.

Lewis, B.P. & Lindner, D.E. (1997). Thinking about choking? Attentional processes and paradoxical performance. *Personality and Social Psychology Bulletin, 23,* 937-944.

Lieberman, H. R., Bathalon, G. P., Falco, C. M., Morgan III, C. A., Niro, P. J., & Tharion, W. J. (2005). The fog of war: Decrements in cognitive performance and mood associated with combat-like stress. *Aviation, Space, and Environmental Medicine, 76*, C7-C14.

Lieberman, H. R., Niro, P., Tharion, W. J., Nindle, B. C., Castellani, W. J., & Montain, S. J. (2006). Cognition during sustained operations: comparison of a laboratory situation to field studies. *Aviation, Space, and Environmental Medicine, 77,* 929-935.

Lindenberger, U., Marsiske, M., & Baltes, P. B. (2000). Memorizing while walking: Increase in dual-task costs from young adulthood to old age. Psychology and Aging, 15, 417–436.

Lyons, M., Al-Nakeeb, Y., & Nevill, A. (2006). Performance of soccer passing skills under moderate and high-intensity localized muscle fatigue. *Journal of Strength and Conditioning Research, 20*, 197-202.

Mahoney, C. R., Hirsch, E., Hasselquist, L., Lesher, L. L., & Lieberman, H. R. (2007). The effects of movement and physical exertion on soldier vigilance, *Aviation, Space, and Environmental Medicine, 78,* B51-B57.

Maki, B. E. (1997). Gait changes in older adults: Predictors of falls or indicators of fear? *Journal of the American Geriatrics Society, 45*, 313–325.

Mann, D. L., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual cognitive expertise in sport: A meta-analysis. *Journal of Sport & Exercise Psychology, 29,* 457-478.

March, S. T., & Smith, G. F. (1995). Design and natural science research on information technology. *Decision Support Systems, 15,* 251-266.

Martin, J. J., Craib, M., & Mitchell, V. (1995). The relationships of anxiety and self-attention to running economy in competitive male distance runners. *Journal of Sports Sciences, 13*, 371–376.

Martin, M. W. & Ellis, J. E. (2012). Human Behavior Representation of Military Teamwork: Amazon.com: Kindle Store.

Mastroianni, G. R., Zupan, M. F., Chuba, D. M., Berger, R. C., & Wile, A. L. (2003).Voluntary pacing and energy cost of off-road cycling and running. *Applied Ergonomics, 31*, 479-485.

Matthews, G., Desmond, P.A., Neubauer, C.E., & Hancock, P.A. (Eds.) (2012). Handbook of operator fatigue. Aldershot, UK.: Ashgate Publishing.

McAndrew, P. M., Dingwell, J. B., & Wilken, J. M. (2010). Walking variability during continuous pseudo-random oscillations of the support surface and visual field. *Journal of Biomechanics, 43*, 1470–1475.

McArdle, W. D., Katch, F. I., & Katch, V. L. (2006). Essentials of exercise physiology (3rd edn.). Baltimore, MD: Lippincott Williams & Wilkins.

McMorris, T. & Graydon, J. (1996a). The effect of exercise on the decision-making performance of experienced and inexperienced soccer players. *Research Quarterly for Exercise and Sport, 67,* 109-114.

McMorris, T. & Graydon, J. (1996b). Effects of exercise on soccer decision-making tasks of differing complexities. *Journal of Human Movement Studies, 30,* 177-193.

McMorris, T. & Hale, B. J. (2012). Differential effects of differing intensities of acute bouts of exercise on speed and accuracy of cognition: A meta-analytical investigation. *Brain and Cognition, 80,* 338-351.

McMorris, T. & Keen, P. (1994). Effect of exercise on simple reaction times of recreational athletes. *Perceptual and Motor Skills, 78,* 123-130.

McMorris, T., Myers, S., MacGillivary, W. W., Sexsmith, J. R., Fallowfield, J., Graydon, J., & Forster, D. (1999). Exercise, plasma catecholamine concentrations and decision-making performance of soccer players on a soccer-specific test. *Journal of Sports Sciences, 17,* 667-676.

Meador, D. P. & Hill, R. R. (2011). Modeling training effects using a human performance taxonomy. *Human Factors, 53,* 391-402.

Midgley, A. W., McNaughton, L. R., & Carroll, S. (2007). Effect of the VO_2 time-averaging interval on the reproducibility of VO_2max in healthy athletic subjects. *Clinical Physiology and Functional Imaging, 27,* 122–125.

Moskaliuk, J., Bertram, J., & Cress, U. (2013). Training in virtual environments: Putting theory into practice. *Ergonomics, 56,* 195–204.

Morrison, J. E. (2003). A review of computer-based human behavior representations and their relation to military simulations. Alexandria, VA, USA : Institute for Defence Analyses (IDA).

Morton, R. H., Fitz-Clarke, J. R., & Banister, E. W. (1990). Modeling human performance in running. *Journal of Applied Physiology, 69,* 1171-1177.

Mullen, R., Hardy, L., & Tattersall, A. (2005). The effects of anxiety on motor performance: a test of the conscious processing hypothesis. *Journal of Sport & Exercise Psychology, 27,* 212-225.

Murray, N. P., & Janelle, C. M. (2003). Anxiety and performance: a visual search examination. *Journal of Sport & Exercise Psychology, 25,* 171-187.

Nadkarni, N. K., Zabjek, K., Lee, B., McIlroy, W. E., & Black, S. E. (2010). Effect of working memory and spatial attention tasks on gait in healthy young and older adults. *Motor Control, 14,* 195–210.

Nieuwenhuys, A., & Oudejans, R. (2010). Effects of anxiety on handgun shooting behavior of police officers: A pilot study. *Anxiety, Stress and Coping, 23,* 1–9. doi:10.1080/10615800902977494.

Nieuwenhuys, A., & Oudejans, R. R. D. (2011). Training with anxiety: Short- and long-term effects on police officers’ shooting behavior under pressure. *Cognitive Processing, 12,* 277–288. doi:10.1007/s10339-011-0396-x.

Nieuwenhuys, A. & Oudejans, R. R. D. (2012). Anxiety and perceptual-motor performance: towards an integrated model of concepts, mechanisms, and processes. *Psychological Research, 76,* 747-759. doi:10.1007/s00426-011-0384-x.

Nieuwenhuys, A., Pijpers, J. R., Oudejans, R. R. D., & Bakker, F. C. (2008). The influence of anxiety on visual attention in climbing. *Journal of Sport and Exercise Psychology, 30*, 171–185.

Nieuwenhuys, A., Savelsbergh, G.J.P., & Oudejans, R.R.D. (2012). Shoot or don't shoot? Why police officers are more inclined to shoot when they are anxious. *Emotion, 12,* 827-833.

Noakes, T. D. (2012). Fatigue is a brain-derived emotion that regulates the exercise behavior to ensure the protection of whole body homeostasis. *Frontiers in Physiology, 3,* 1-13.

Oudejans, R. R. D. (2008). Reality-based practice under pressure improves handgun shooting performance of police officers. *Ergonomics, 51,* 261–273.

Oudejans, R. R. D., Kuipers, W., Kooijman, C. C., & Bakker, F. C. (2011). Thoughts and attention of athletes under pressure: Skill-focus or performance worries. *Anxiety, Stress and Coping, 24,* 1–15. doi:10.1080/10615806.2010.481331.

Oudejans, R. R. D., Michaels, C. F., van Dort, B., & Frissen, E. J. P. (1996). To cross or not to cross: The effect of locomotion on street-crossing behavior. *Ecological Psychology, 8,* 259–267.

Oudejans, R. R. D., & Pijpers, J. R. (2009). Training with anxiety has a positive effect on expert perceptual-motor performance under pressure. *Quarterly Journal of Experimental Psychology, 62,* 1631–1647. https://dx.doi.org/10.1016/j.psychsport.2009.05.002.

Oudejans, R. R. D., & Pijpers, J. R. (2010). Training with mild anxiety may prevent choking under higher levels of anxiety. *Psychology of Sport and Exercise, 11*, 44–50. doi:10.1016/j.psychsport.2009.05.002.

Oudejans, R. R. D., van de Langeberg, R. W., & Hutter, R. I. (2002). Aiming at a far target under different viewing conditions: visual control in basketball jump shooting. *Human Movement Science, 21*, 457-480.

Pijpers, J. R., Oudejans, R. R. D., & Bakker, F. C. (2005). Anxiety-induced changes in movement behavior during the execution of a complex whole-body task. *Quarterly Journal of Experimental Psychology A, 58,* 421–445.

Pijpers, J. R., Oudejans, R. R. D., & Bakker, F. C. (2007). Changes in the perception of action possibilities while climbing to fatigue on a climbing wall. *Journal of Sports Sciences, 25*, 97–110.

Pijpers, J. R., Oudejans, R. R. D., Holsheimer, F., & Bakker, F. C. (2003). Anxiety–performance relationships in climbing: A process-oriented approach. *Psychology of Sport and Exercise*, *4*, 283–304.

Proffitt, D. R., Bhalla, M., Gossweiler, R., & Midgett, J. (1995). Perceiving geographical slant. *Psychonomic Bulletin & Review, 2,* 409–428.

Proffitt, D. R. & Linkenauger, S. A. (2013). Perception viewed as a phenotypic expression. In *Action Science: Foundations of an Emerging Discipline,* edited by W. Prinze, M. Beisert, & A. Herwig, 171–198. Cambridge, MA: MIT Press.

Rognum, T. O., Vartdal, F., Rodahl, K., Opstad, P. K., Knudsen-Baas, O., Kindt, E., & Whitey, W. R. (1986). Physical and mental performance of soldiers on high- and low-energy diets during prolonged heavy exercise combined with sleep deprivation. *Ergonomics, 29,* 859-867.

Royal, Farrow, Mujika, Halson, Pyne, & Abernethy, (2006). The effects of fatigue on decision making and shooting skill performance in water polo players. *Journal of Sports Sciences, 24,* 807-815.

Sanders, A. F. (1986). Energetical states underlying task performance. In *G. R. J. Hockey,A. W. K. Gaillard, & M. G. H. Coles (Eds.), Energetics and human information processing* (pp. 139-154). Dordrecht: Matinus Nijhoff.

Saunders, P. U., Pyne, D. B., Telford, R. D., & Hawley, J. A. (2004). Factors affecting running economy in trained distance runners. *Sports Medicine, 34*, 465–485.

Schieb, D. A. (1986). Kinematic accommodation of novice treadmill runners. *Research Quarterly for Exercise and Sport, 57*, 1–7.

Schücker, L., Hagemann, N., Strauss, B., & Volker, K. (2009). The effect of attentional focus on running economy. *Journal of Sports Sciences, 27,* 1241–1248.

Selfridge, O. G. (1958). Pandemonium: a paradigm for learning. Mechanisation of thought processes: proceedings of a symposium held at the National Physical Laboratory, London: HSMO, pp. 513-526.

Silverman, B.G. (2001). More Realistic Human Behavior Models for Agents in Virtual Worlds: Emotion, Stress, and Value Ontologies. University of Pennsylvania: Philadelphia.

Seo, N. J. (2009). Dependence of safety margins in grip force on isometric push force levels in lateral pinch. *Ergonomics, 52,* 840–847.

Smith, N. C., Bellamy, M., Collins, D. J., & Newell, J. (2001). A test of processing efficiency theory in a team sport context. *Journal of Sports Sciences, 19,* 321–332.

Spielberger, C.S. (1966).Theory and research on anxiety. In *Anxiety and behavior* (edited by C.S. Spielberger), pp. 3-20. New York: Academic Press.

Stefanucci, J. K., Proffitt, D. R., Clore, G., & Parekh, N. (2008). Skating down a steeper slope: Fear influences the perception of geographical slant. *Perception, 37,* 321-323.

Stevens, J. (1996). Applied multivariate statistics for the social sciences (3rd ed.). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Stins, J. F., Roelofs, K., Villan, J., Kooijman, K., Hagenaars, M. A., & Beek, P. J. (2011). Walk to me when I smile, step back when I'm angry: Emotional faces modulate whole-body approach-avoidance behaviors. *Experimental Brain Research, 212,* 603-611.

Suss, J. & Ward, P. (2010). Skill-based differences in the cognitive mechanisms underlying failure under stress. In *Proceedings of the Human Factors and Ergonomics Society 54th annual meeting*, San Francisco, September, 1062-1066.

Tharion, W. J., Montain, S. J., O'Brien, C., Shipps, R. L., & Hoban, J. L. (1997). Effects of military exercise tasks and a carbohydrate-electrolyte drink on rifle shooting performance in two shooting positions. *International Journal of Industrial Ergonomics, 19,* 31–39.

Tomporowski, P. D. (2003). Effects of acute bouts of exercise on cognition. *Acta Psychologica, 112,* 297-324.

Ubink, E., Aldershoff, F., Lotens, W., & Woering, A. (2008). Behavior modeling through CHAOS for simulation of dismounted soldier operations. Modeling and Simulation for Military Operations III, Orlando, FL, USA. Proceedings of the SPIE – Society of Photo-optical Instrumentation Engi, 2008.

Ubink, E., Lotens, W., Woering, A. (2010). Towards a generic behavior modeling interface. RTO-MP-HFM-202.

Van der Ploeg, H. M., Defares, P. B., & Spielberger, C. D. (1980). Manual for the Dutch version of the State–Trait Anxiety inventory. Lisse, Netherlands: Zwets & Zeitlinger.

Van Lent, M., McAlinden, R., Brobst, P., Silverman, B. G., O'Brien, K., & Cornwell, J. (2004). Enhancing the behavioral fidelity of synthetic entities with human behavior models. 13th Conference on Behavior Representation in Modeling and Simulation (BRIMS), SISO, May 12-15, 2004.

Veltman, J. A., & Gaillard, A. W. (1993). Indices of mental workload in a complex task environment. *Neuropsychobiology, 28*, 72–75.

Vickers, J. N. (1996). Visual control when aiming at a far target. *Journal of Experimental Psychology: Human Perception & Performance, 22*, 342-354.

Vickers, J. N., Rodrigues, A. T., & Edworthy, G. (2000). Quiet eye and accuracy in the dart throw. *International Journal of Sports Vision, 6*, 30-36.

Vickers, J. N., & Williams, A. M. (2007). Performing under pressure: The effects of physiological arousal, cognitive anxiety, and gaze control in biathlon. *Journal of Motor Behavior, 39*, 381–394. doi:10.3200/JMBR.39.5.381-394.

Vine, S. J., Moore, L. J., & Wilson, M. R. (2011). Quiet eye training facilitates competitive putting performance in elite golfers. *Frontiers in Psychology, 2*, 1-9. doi:10.3389/fpsyg.2011.00008.

Vine, S. J., & Wilson, M. R. (2010). Quiet eye training: effects on learning and performance under pressure. *Journal of Applied Sport Psychology, 22*, 361-376. doi:10.1080/10413200.2010.495106.

Vine, S. J., &Wilson, M. R. (2011). The influence of quiet eye training and pressure on attention and visuo-motor control. *Acta Psychologica, 136*, 340-346. doi:10.1016/j.actpsy.2010.12.008.

Wall, J. C., & Charteris, J. (1980). The process of habituation to treadmill walking at different velocities. *Ergonomics, 23*, 425–435.

Wall, J. C., & Charteris, J. (1981). A kinematic study of long term habituation to treadmill walking. *Ergonomics, 24*, 531–542.

Ward, P., Farrow, D., Harris, K. R., Williams, A. M., Eccles, D. W., & Ericsson, K. A. (2008). Training perceptual-motor skills: Can sport psychology research inform military decision training? *Military Psychology, 20*, S71-S102.

Warren, W. H. & Whang, S. (1987). Visual guidance of walking through apertures: Body-scaled information of affordances. *Journal of Experimental Psychology: Human Perception & Performance, 13*, 371–383.

Williams, A. M., & Elliott, D. (1999). Anxiety, expertise, and visual search strategies in Karate. *Journal of Sport & Exercise Psychology, 21*, 362-375.

Williams, A.M., Vickers, J., & Rodrigues, S. (2002). The effects of anxiety on visual search, movement kinematics, and performance in table tennis: A test of Eysenck and Calvo's processing efficiency theory. *Journal of Sport and Exercise Psychology, 24*, 438–455.

Wilson, K. A., Salas, E., Priest, H. A., & Andrews, D. (2007). Errors in the heat of battle: Taking a closer look at shared cognition breakdowns through teamwork. *Human Factors, 49*, 243-256.

Wilson, M. R. (2008). From processing efficiency to attentional control: A mechanistic account of the anxiety-performance relationship. *International Review of Sport and Exercise Psychology, 1*, 184-201.

Wilson, M. R., Chattington, M., Marple-Horvat, D. E., & Smith, N. C. (2007). A comparison of self-focus versus attentional explanations of choking. *Journal of Sport and Exercise Psychology, 29,* 439–456.

Wilson, M. R., Vine, S. J., & Wood, G. (2009a). The influence of anxiety on visual attentional control in basketball free throw shooting. *Journal of Sport and Exercise Psychology, 31,* 152–168.

Wilson, M. R., Wood, G., & Vine, S. J. (2009b). Anxiety, attentional control, and performance impairment in penalty kicks. *Journal of Sport and Exercise Psychology, 31,* 761–775.

Wood, G., & Wilson, M. R. (2011). Quiet-eye training for soccer penalty kicks. *Cognitive Processing,* 257-266. doi:10.1007/s10339-011-0393-0.

Wray, R. E., & Laird, J. E. (2003). Variability in human behavior modeling for military simulations. In *Proceedings of Behavior Representation in Modeling and Simulation Conference (BRIMS).*

Yang, Y. R., Chen, Y. C., Lee, C. S., Cheng, S. J., & Wang, R. Y. (2007). Dual-task-related gait changes in individuals with stroke. *Gait and Posture, 25,* 185–190.

Yerkes, R.M. & Dodson, J.D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology, 18,* 459-482.

Zijlstra, F. R. H. (1993). Efficiency in work behavior: A design approach for modern tools. Doctoral dissertation, Technical University Delft. Delft, Netherlands: Delft University Press.

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Curriculum Vitae

Nicky Nibbeling was born on November 9th 1982 in Maastricht, The Netherlands. After finishing secondary school (VWO, profiel ‘Natuur en Techniek’) at the Eurocollege in Maastricht in 2001, she started with the study BioMedical Engineering at Eindhoven University of Technology. She graduated as a Bachelor of Science in 2006. In that same year she began with the Sport Psychology Masters program at the Faculty of Human Movement Sciences of the VU University Amsterdam. She conducted her Master internship on the use of imagery by elite canoe-slalom athletes in la Sue d’Urgell, Spain in 2008. In September 2009 she commenced with her PhD project at the VU University Amsterdam in collaboration with the Training Innovations & Performance department at TNO Soesterberg. The results of this project are described in this thesis. Next to her scientific interest, she is also engaged in human movement and sport psychology in practice. As a professional white-water canoe athlete she took part in World Cups from 2001 to 2009 and she was a medalist at both the European and World championships in white-water rafting in 2011. Currently, Nicky lives in Utrecht, together with her boyfriend Angelo and her daughter Fajah (7 months).