Psychomotor speed as a marker for overtraining in athletes
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Chapter 2

The effect of two maximal exercise bouts on reaction time in a response preparation task in athletes

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Exercise facilitates complex reaction times. It is unknown if the ability to prepare responses is affected by exercise. As many athletes practice or compete more than once a day, the purpose of the present study was to investigate the effect of two maximal exercise bouts on reaction time with or without response cuing. Thirteen subjects performed the finger pre-cuing task before and after two maximal incremental graded treadmill runs on one day. This exercise trial was counterbalanced with a control trial in which the same subjects sat quietly instead of running. A significant interaction effect between time and trial was found, showing shorter reaction times on the finger pre-cuing task after exercise but not after rest. The facilitative effect of exercise was the same for all cuing conditions, indicating that exercise affected the motor and not the premotor component of reaction time. Furthermore, the facilitative effect was the same for the first and the second exercise bout, consistent with the fact that subjects showed full recovery between exercise bouts.
**INTRODUCTION**

Complex reaction times are an important aspect of elite sports. A goalkeeper has to decide in an instant which part of the goal to defend. A tennis player must rapidly react to the serve of the opponent. A judoka must react fast to an attack. In all cases the athlete reacts to a complex stimulus situation. One of the questions that rise, is whether or not the reaction times of these athletes are influenced by exercise.

In the past fifteen years many researchers have investigated the effect of exercise on choice reaction times. In most studies a facilitative effect was shown (Adam et al., 1997; Arcelin et al., 1997; Arcelin et al., 1998; Chmura et al., 1994; Chmura et al., 1998; Davranche et al., 2006a; Davranche & Audiffren, 2004; Kashihara & Nakahara, 2005; McMorris et al., 1999; McMorris et al., 2005b; McMorris & Graydon, 1996a; McMorris & Graydon, 1996b; McMorris & Graydon, 1997). In some studies no effect (Hogervorst et al., 1996; Lemmink & Visscher, 2005; Travlos & Marisi, 1995) or even a debilitative effect of exercise on complex reaction time was found (Delignieres et al., 1994; Guizani et al., 2006; McMorris et al., 2005a).

In many studies choice reaction time tasks were used in which stimulus and response were compatible. Results of these studies are mixed, facilitative, debilitative and no effect has been found (Arcelin et al., 1997; Collardeau et al., 2001; Davranche et al., 2005; Davranche et al., 2006a; Delignieres et al., 1994; Guizani et al., 2006; Lemmink & Visscher, 2005; McMorris et al., 2005a; McMorris et al., 2005b; Travlos & Marisi, 1995). The question is, how relevant compatible stimulus response tasks are for the sport situation. In many situations the athlete will have to react with a more incompatible response, for example in the case of a feint. However, in the two studies in which the effect of stimulus response compatibility was investigated, no interaction of exercise with stimulus compatibility was found (Davranche & Audiffren, 2004; Hogervorst et al., 1996).

In studies using other reaction time paradigms a consistent facilitative effect was found. One of these paradigms is the inclusion of false stimuli that should be inhibited. Chmura et al. (1994; 1998) used a reaction time task in which two true, positive and two false, negative stimuli appeared in random order. They found a facilitative effect of exercise up to maximal workloads where reaction times increased suddenly. Another paradigm in which consistent facilitative effects have been found is the decision making paradigm (Adam et al., 1997; Kashihara & Nakahara, 2005; McMorris et al., 1999; McMorris & Graydon, 1996a; McMorris & Graydon, 1996b; McMorris & Graydon, 1997; Paas & Adam, 1991). In this kind of reaction time tasks the stimulus needs to be processed before the correct response can be selected and executed. In sports situations this will often be the case. The goal keeper will have to process a complex set of stimuli from which he should deduct the most appropriate response. In many cases, however, the athlete, whether it is the goalkeeper, the tennis player or the judoka, will get some kind of cue that reduces the amount of possible responses (Williams & Starkes, 2002).

Response cuing can be examined in computerised reaction time tasks, for example in the so-called finger pre-cuing task (FPT; Adam et al.,
The FPT is a choice reaction time task in which four stimulus/response locations are reduced to two stimulus/response locations by a pre-cue, allowing the selective preparation of a subset of two possible finger responses. It has consistently been shown that this advance preparation produces substantially shorter reaction times compared to a control condition (i.e., the uncued condition) which does not allow advance preparation (Adam et al., 2003; Miller, 1982). The magnitude of the pre-cuing advantage depends on the kind of pre-cue and on the time interval between the pre-cue and the actual stimulus. An important feature of this task is the fact that it involves selective stimulus detection and selective motor preparation (Adam & Pratt, 2004). We are not aware of any studies into the effect of physical exercise on selective response preparation.

Another issue that arises in sports practice, is the fact that athletes train or even compete more than once a day. It is relevant to investigate whether the effect of exercise on complex reaction time differs between a first and a second exercise bout. This could have implications especially for training practice. If the effect of exercise on finger pre-cuing reaction time with or without response cuing differs between the first and the second bout, one would like to adjust the order of different practice sessions to match the competition situation. For example, in football only one game per day is played. It would thus be most relevant to do football specific practice sessions first. In other sports, such as judo, more than one fight a day is common. The training schedule should therefore likewise be adjusted.

The purpose of the present study was to investigate the effect of two maximal exercise bouts on choice reaction time in a response preparation task and investigate whether this relation is different for uncued (i.e., no selective response preparations) and cued (i.e., with selective response preparation) conditions. A stronger facilitative effect of exercise on the cued compared to the uncued condition would support a central response preparation locus, whereas a general facilitative effect would support a more peripheral, motor locus. This hypothesis is based on the notion that RT can be partitioned into two components: a “central” component reflecting central, cognitive processes involved in decision making and response selection, and a “motor” component representing more peripheral processes associated with recruiting and activating the muscles needed to execute the motor response.

**Methods**

**Subjects**

11 Male and 2 female middle and long distance athletes participated in the study. Subjects were 27.2 (SD = 8.6) years old, their length was 183.9 (SD = 5.2) cm, their weight was 73.5 (SD = 5.2) kg. Subjects trained for 4.27 (SD = 2.49) hours per week on average and had 5.6 (SD = 3.9) years of running experience. Subjects were informed about the procedures of the study before they gave their informed consent to participate. Procedures were in accordance with the medical and ethical standards of the Helsinki Declaration.
Maximal Treadmill Runs
The treadmill runs were performed on a motor driven treadmill (Enraf-Nonius, Delft, the Netherlands) in our laboratory. The run started at a speed of 10 km/h for men and 8 km/h for women. The speed was increased every 5 min by 1 km/h until a speed of 14 km/h was reached. From here the gradient was increased with 1% every five minutes until volitional exhaustion. Heart rate was monitored with a sports tester (Polar Accurex Plus, Kempele, Finland) and was stored every 5 s. The highest heart rate over 5 s was taken as maximal heart rate. Borg’s 15-grade rating of perceived exertion (Borg, 1998) was administered at the end of the test. Before and immediately after the treadmill runs a blood sample was taken from the right earlobe. The sample was analysed immediately for lactate concentration (YSI 2300, Yellow Springs, Ohio).

Finger Pre-cuing Task
Reaction times were measured using the FPT (Adam et al., 2003; Miller, 1982). Subjects respond to stimuli displayed on a computer screen with button press responses by index and middle fingers of both hands, placed on four keys of the computer keyboard (the two left most and two right most keys on the bottom row of the keyboard). Stimuli were plus (+) signs shown in the middle of the computer screen. The stimulus display consisted of a warning signal, a cue signal and a target signal. The warning signal was a row of four plus signs. After a delay of 750 ms the cue signal appeared immediately below the warning signal. After 500 ms (the preparation interval) the target signal appeared on the computer screen in a position indicated by the cue. The target signal consists of one plus sign indicating the final target location. Four pre-cue conditions were distinguished. In the uncued condition the cue signal consisted of four plus signs in all four positions, preventing the possibility of selective response preparation. In the hand cued condition the cue signal consisted of two plus signs at the two left most or the two right most positions, indicating the middle and index fingers of the left or the right hand respectively. In the finger cued condition the cue signal consisted of two plus signs at the two outer or the two inner positions, indicating the two middle or the two index fingers. In the neither cued condition the cue signal indicated the middle and index fingers of different hands. An inter trial interval of 1000 ms separated the response in a trial from the start of the next trial. One test consisted of 160 trials, with 40 trials for each of the four cue conditions in random order. Subjects were informed about the nature of the task and were explicitly told to take advantage of the cue stimuli. Subjects were instructed to respond as quickly as possible to the position in which the target signal occurred by pressing the appropriate response button. Error feedback was provided on individual trials.

Total Quality of Recovery
Recovery between the two treadmill runs was measured every half hour using the total quality of recovery scale (Kenttä & Hassmén, 1998). The scale is a 15-grade rating scale (6-20) based on Borg’s rating of perceived exertion scale (Borg, 1998).
EXPERIMENTAL DESIGN

A cross-over design was used, all subjects participated in two trials: one exercise and one control trial. The trials were performed in different weeks and the order was counterbalanced. A week before participating in the study participants were screened by a physician and a maximal incremental cycling test with ECG-registration was performed to identify potential contraindications for participation. None of the subjects was excluded on basis of the screening or the ECG. At the same day subjects also performed two finger pre-cuing task practice sessions.

In the exercise group subjects performed two maximal treadmill runs on the same day separated by 3 hours rest. In the morning subjects started with two finger pre-cuing tasks, a practice session and the first pre intervention session. This was followed by the first maximal treadmill run. Immediately after cessation subjects performed the first post intervention finger pre-cuing task. In the three hours rest period subjects were provided with high carbohydrate food and drinks and were encouraged to relax. The total quality of recovery scale was administered every 30 min.

After the rest period subjects performed the second pre intervention finger pre-cuing session followed by the second maximal treadmill run, immediately followed by the second post intervention finger pre-cuing session. The control group followed the same protocol, but were studying or reading instead of running.

DATA ANALYSIS

All data were analysed with SPSS 11.01. All data are presented as group means ± standard deviations. An ANOVA for repeated measures with test (first versus second intervention), time (before versus after intervention), and finger pre-cuing condition (uncued, hand cued, finger cued and neither cued) and trial (exercise versus control trial) as within subject factors was used to evaluate the effect of the intervention on reaction times. T tests were used for post-hoc analysis with a Bonferoni correction for multi comparisons (i.e. the p values were compared to α = .05 divided by the number of comparisons).

RESULTS

MAXIMAL TREADMILL RUNS

The mean duration of both the first and the second treadmill run was 34 min (SD = 10 and SD = 12 min respectively). Mean maximal heart rates, post exercise blood lactate concentrations and maximal ratings of perceived exertion were 189 (SD = 7) bpm, 8.0 (SD = 2.1) mmol/l and 18.9 (SD = 0.5) for the first test and 188 (SD = 10) bpm, 6.8 (SD = 2.0) mmol/l and 18.9 (SD = 0.6) for the second maximal treadmill run. Paired samples t tests (α ≤ .01) showed that the duration of the test, maximal heart rates, post exercise blood lactate concentrations and maximal ratings of perceived exertion did not differ from the first to the second test.
Recovery Between Treadmill Runs

Subjects felt a reasonable recovery (i.e. a mean score of 13 on a 6-20 scale) after half an hour of rest and good recovery after one hour (i.e. a score of 15). Scores on the total quality of recovery scale did not rise anymore after the first hour. A t test showed that the pre exercise lactate values, 1.47 (± 0.50) and 1.62 (± 0.39) mmol/l, did not differ from each other.

Finger Pre-cuing Task

Mean reaction times at the FPT can be found in Table 2.1. A repeated measures ANOVA showed significant main effects for test (first vs. second intervention), $F(1,12) = 8.53$, time (before vs. after intervention), $F(1,12) = 20.14$, and pre-cuing condition, $F(3,36) = 44.41$ (Figure 2.1). The main effect for test indicated shorter reaction times before and after the second intervention compared to the first. The main effect of time indicated shorter reaction times after the intervention compared to before the intervention. This effect is explained by an interaction effect. Post hoc t tests for pre-cuing conditions ($\alpha \leq .01$) revealed that reaction times in the uncued condition were significantly longer than the hand cued, $t(12) = 14.39$, finger cued, $t(12) = 10.62$, and the neither cued condition, $t(12) = 6.11$. Reaction times in the hand cued and the finger cued condition were significantly shorter than the neither cued condition, $t(12) = 3.59$, $t(12) = -5.35$ respectively. The reaction times of the hand and the finger cued conditions did not differ significantly from each other.

A significant interaction effect was found between time (before vs. after intervention) and trial (exercise vs. control trial), $F(1,12) = 19.27$ (Figure 2.2). T tests ($\alpha \leq .02$) showed that only in the exercise trial there was a difference in reaction times.

<table>
<thead>
<tr>
<th>CUING CONDITION</th>
<th>Test 1</th>
<th>Test 2</th>
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<tbody>
<tr>
<td></td>
<td>EXP TRIAL</td>
<td>CON TRIAL</td>
</tr>
<tr>
<td><strong>PRE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncued</td>
<td>379 (±48)</td>
<td>382 (±43)</td>
</tr>
<tr>
<td>Hand</td>
<td>314 (±40)</td>
<td>317 (±37)</td>
</tr>
<tr>
<td>Finger</td>
<td>331 (±58)</td>
<td>331 (±61)</td>
</tr>
<tr>
<td>Neither</td>
<td>347 (±65)</td>
<td>342 (±59)</td>
</tr>
<tr>
<td><strong>POST</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncued</td>
<td>354 (±47)</td>
<td>380 (±46)</td>
</tr>
<tr>
<td>Hand</td>
<td>293 (±37)</td>
<td>313 (±29)</td>
</tr>
<tr>
<td>Finger</td>
<td>306 (±57)</td>
<td>328 (±51)</td>
</tr>
<tr>
<td>Neither</td>
<td>323 (±60)</td>
<td>349 (±61)</td>
</tr>
</tbody>
</table>
Results showed that RTs in all cued conditions (hand- finger- and neither-cued conditions) were substantially faster than RTs in the uncued condition, indicating that subjects did engage in selective response preparation, as is usually found (Adam et al., 2003). The key finding of this study was that exercise facilitated reaction time performance regardless of cue condition. This finding suggests that exercise did not specifically benefit selective response preparation processes. It benefitted a more general component of reaction time, namely the peripheral motor component responsible for executing the response. Previous studies have indeed shown that exercise shortens the motor component of reaction time. Davranche and colleagues (Davranche et al., 2005; Davranche et al., 2006b) consistently showed shorter intervals between EMG onset and actual responses (i.e., button press) during exercise.

However, some effects on the pre motor component have also been found (Davranche et al., 2005; Yagi et al., 1999). Davranche and colleagues (Davranche et al., 2005) found that exercise positively influenced pre motor time only in a high intensity stimulus condition. The results indicated that different parallel processes were affected by exercise and stimulus intensity. Yagi and colleagues (Yagi et al., 1999) measured EEG during a study into the effects of exercise on visual and auditory oddball tasks. They found decreased P300 latencies and amplitudes. The decreased P300 latencies indicated faster stimulus evaluation. The
decreased P300 amplitudes indicated decreased attention (Yagi et al., 1999). Occurrence of such counterbalancing effects on response preparation can therefore not be excluded in the present study.

The second part of the research question concerned the effect of two exercise bouts on one day on complex reaction times. Reaction time was therefore assessed after two maximal treadmill runs on one day. A main effect of test was found. Subjects were faster before and after the second intervention compared to the first intervention in both the exercise and the control trial. As this effect was not different between trials, the effect can not be ascribed to the second of two exercise bouts. Instead, the effect must most likely be ascribed to practice effects. Reaction times were 14 ms shorter on the second compared to the first day of participation, irregardless trial order.

The facilitative effects on choice reaction time were the same for the first and the second exercise bout. Indeed, performance parameters did not differ between the first and the second bout. Duration of the test, maximal heart rate, post exercise blood lactate concentration and maximal rating of perceived exertion did not differ between the first and the second treadmill run. Additionally, subjects reported high ratings of perceived quality of recovery between treadmill runs. Pre-exercise blood lactate concentrations did also not differ between treadmill runs. It can thus be concluded that subjects were fully recovered from the first bout before entering the second.

Figure 2.2. Mean reaction times before and after the exercise and control interventions. * = Significant difference.
The two exercise bouts in the present study were relatively short compared to the length of typical training sessions. On the other hand, the rest period of three hours was much longer compared to, for example, half time in a football match. It is interesting to investigate whether the influence of a match or two training sessions a day on reaction time is similar to the facilitating results in the present study. It can be concluded that exercise facilitated choice reaction time in cued as well as in uncued conditions. This finding suggests a facilitative effect on the peripheral, motor component of reaction time. Additionally, the positive effect of physical exercise on choice reaction time was the same for two exercise bouts on one day.