Ger J Exerc Sport Res 2018 · 48:341–348
https://doi.org/10.1007/s12662-018-0514-3
Received: 2 December 2017
Accepted: 20 March 2018
Published online: 23 April 2018

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Football practice with youth players in the "Footbonaut"

Speed of action and ball control in face of physical and mental strain

Introduction

To accelerate the characteristics and eventually benefit the chances of winning sports games, coaches continuously aim to improve, amongst other things, their players' tactical and technical skills. With this, today's daily practice and—more importantly—talent identification and development require sport-specific performance diagnostic systems. Considered as a controlled state-of-the-art performance diagnostic system in football, the "Footbonaut" (currently applied in leading training centres of German Bundesliga clubs) has been suggested to quantify physical and mental components of agility that are particularly suitable for talent identification and development, including speed of action and ball control (Saal, Zinner, Büsch, Werner, & Ückert, 2013).

While speed of action is well accepted to reliably demonstrate an efficient agility and, thus, indicate high-performance skill levels in football players (Saal et al., 2013; Weineck, 2004), ball control and passing accuracy that are performed in accordance with a situational perception are considered to be important basic skills (Bisanz & Gerisch, 2008; Hyballa & te Poel, 2015). Moreover, previous research reported the majority of goals to be scored after assistive passing (Michailidis, Michailidis, & Primpa, 2013; Olsen, 1986; Sajadi & Rahnama, 2007). In addition, winning teams competing in elite football have been shown to successfully complete more passes than losing teams (Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2009). This is, however, different for short passing performances in youth players, which has been suggested to result from physical (Rampinini et al., 2007) and possibly mental signs of fatigue (e.g. intermittently induced psychological stress during a game; Nédélec et al., 2012; Walsh, 2014).

Resulting from physical and mental strain, fatigue is described as a multidimensional construct, which, well accepted, has recently been reported to show negative effects on sports performance (Knicker, Renshaw, Oldham, & Cairns, 2011). Reversible signs of physical fatigue (Bangsbo, Madsen, Kiens, & Richter, 1996; Fitts, 2006; Krustrup et al., 2003; Westerblad, Allen, & Lännergren, 2002) have been discussed to occur temporarily (Hohmann, Lames, & Letzelter, 2002; Noakes & Gibson, 2004; Schnabel, 2008) and particularly towards the end of a sports performance (i.e. a game), which is suggested to result from intermittent exposures to physical strain (Krustrup et al., 2006; Mohr, Krustrup, & Bangsbo, 2003). To induce in particular football-specific signs of physical fatigue, high-intensity training (HIT; Bradley et al., 2009; Bradley, Di Mascio, Peart, Olsen, & Sheldon, 2010) intervals (e.g. on small-sided fields) are well accepted to increase heart rates (HR) or lactate concentration (Selmi et al., 2017). Further, there is evidence showing that 4 × 4 HIT intervals intensify a physiological activation, e.g. an even more acute increase in HR (Wiewelhove et al., 2016). More recently, reversible signs of mental fatigue (Van Cutsem et al., 2017) have been reported to result from prolonged periods of cognitively demanding activity (Boksem & Tops, 2008; Marcora, Staiano, & Manning, 2009), causing attentional disturbances and refocussing in players (Ackerman, 2011; Boksem, Meijman, & Lorist, 2006). Recent research provides evidence that different factors of football performance have been negatively affected subsequent to induced mental strain (e.g. the Stroop task; Smith et al., 2016a, b): Short passing accuracy assessed by the Loughborough Soccer Passing Test (LSPT) was impaired, whereas speed of action was not modulated in 14 experienced Belgian league football players (divisions 2 to 7; Smith, Fransen, Deprez, Lenoir, & Coutts, 2017). Further, both offensive and defensive technical performances on small-sided football fields were shown to decrease subsequent to mental strain (Badin, Smith, Conte, & Coutts, 2016). Krause, Kärcher, Munz, and Brack (2012) further underline the importance of speed of action and ball control for talent identification and development and, thus, the need to control and measure football-specific movement learning and motor behaviour, in particular with respect to players entering or being rejected from youth training centres. Not least an ongiong globalization in talent identification as well as

seemingly unlimited increasing transfer fees for football professionals, this results in more and more professionally acting youth training centres (e.g. controlled performance diagnostics). Thus, controlled Footbonaut speed of action assessments that eventually allow for establishing age-related normed values have been suggested to serve as one criterion for a controlled performance diagnostic in youth football (Saal & Fiedler, 2013).

However, induced physical and mental signs of fatigue on performance diagnostics assessed by controlled state-of-the-art systems (i.e. the Footbonaut) remain to be elucidated and, thus, characterize the purpose of this investigation, particularly addressing football-specific speed of action and ball control as crucial talent identification and development variables in youth players. Based on previous research, it was hypothesized that sport-specific physically and well-established mentally demanding tasks (1) induce physical and mental signs of fatigue, e.g. increased heart rates and self-perceptions compared to a control condition. Accordingly, (2) speed of action and ball control performances were hypothesized to be impaired by physical and mental strain in U14 to U16 youth players, taking their classical positions on the football field into account (e.g. striker, midfielder, defender, goalkeeper).

Methods

Participants

Thirty-three male youth football players (13.5 ± 1.0 years of age, 166.8 ± 8.1 cm height, competitive level) volunteered to participate in this study. Participants competed at the highest regional or national youth level in their respective age group (10.0 ± 1.4 years of experience) and attended grammar school ("Gymnasium" , $n = 20$), comprehensive school ("Gesamtschule", $n = 4$) or secondary modern school ("Realschule", $n = 9$) for higher school education. Prior to the investigation, all participants and their legal guardians provided written informed consent. Conducted at the TSG 1899 Hoffenheim training centre, the study was approved by the Human Research Ethics Committee of the German Sport University Cologne in compliance with the Declaration of Helsinki.

Experimental procedure

Each participant underwent familiarization in the Footbonaut (i.e. performing one practice pattern, 20 balls randomly drawn at 50 km/h) approximately one hour prior to starting the experiment. Participants were randomly assigned into three matched groups: physically demanding tasks (PDT), mentally demanding tasks (MDT) and a control condition (CON). To exclude a potential detrimental effect on short passing ability and a fatigue-related decline in technical proficiency relative to endurance capacities, group matchings took endurance performances into account (Castagna, Impellizzeri, Rampinini, D'Ottavio, & Manzi, 2008; Rampinini et al., 2008; Yo-Yo intermittent recovery test level 1 assessed one week prior to the experiment: PDT with mean running distance [RD] 934.6 ± 249.3 m at mean maximum heart rates [HR] 206.3 ± 6.7 bpm; MDT with mean RD 930.9 ± 273.1 m at mean maximum HR 202.2 ± 7.2 bpm; CON with mean RD 1106.7 ± 272.3 m at mean maximum HR 202.0 ± 4.2 bpm). In the experiment, each participant underwent a standardized warm-up subsequent to a Footbonaut baseline measurement (Footbonaut-1; details on the Footbonaut are provided below), the assigned intervention (PDT, MDT) or CON, and a final Footbonaut measurement (Footbonaut-2). Footbonaut-1 and Footbonaut-2 consisted of 20 balls each, randomly drawn at 50 km/h at ground level. Participants were instructed to control and pass each ball as accurately (goal-directed) and quickly as possible. Heart rates were recorded immediately after baseline, warm-up, Footbonaut-1, interventions (PDT, MDT) or CON, and Footbonaut-2, whereas self-perceptions of fatigue were assessed immediately prior to and after interventions (PDT, MDT) and CON.

Footbonaut

The Footbonaut is considered to be an innovative, state-of-the-art high-tech measuring system for, at least applied, diagnostics and training in football, focusing on agility and passing accuracy (Saal et al., 2013). Main outcome parameters are time of execution and passing precision, referring to football-specific and ball-oriented (re)action tasks. The Footbonaut consists of a 14.0 × 14.0 m play zone (artificial turf), which is surrounded by four walls consisting of 72 high and low positioned square panels (1.40 × 1.40 m), each equipped with light barriers and light-emitting diodes (LED). Two ball-throwing machines (eight in total) are placed behind the middle panel of each wall. The remaining squares serve as targets. Stimuli are given visually (LEDs) and acoustically (signal), pointing out the respective ball-throwing machine (acoustic stimuli) as well as the respective target panel (visual stimuli; **Fig. 1**).

With respect to and serving a lack of evidence in Footbonaut research, the present study intended to compensate for reliability testing, according to its challenges (for details please refer to the statistical analyses and limitations).

Interventions and control condition

Physically demanding task (PDT)

Participants of the PDT group underwent a football-specific course. In the course, participants were instructed to dribble, pass, jump, sprint backwards and forwards as well as to handle a coordinative speed ladder task. The total time to complete the PDT was approximately 28 min, consisting of 4 intervals of 4 min in the course with 3 min of active recovery between intervals (i.e. jogging at self-selected moderate pace). Participants were timed to start PDT with two participants at a time in the course, in order to meet time-matched entrances of the Footbonaut-2 measurements and to avoid recovery periods from physical strain. Participants began the Footbonaut-2 measurement within 1 min (i.e. fast walking from the PDT course to

Abstract · Zusammenfassung

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Football practice with youth players in the "Footbonaut". Speed of action and ball control in face of physical and mental strain

Abstract

In today's leading football training centres, state-of-the-art performance diagnostic systems such as the "Footbonaut" allow controlled and standardized assessments of physical and mental components of agility, e.g. speed of action and ball control, that are considered to be decisive for talent identification and development. However, effects of induced physical and mental strain on performing football-specific practice patterns remain to be elucidated, particularly in youth players, and, thus, characterize the purpose of this study. 33 randomly assigned competitive football players (U14 to U16) performed a standardized Footbonaut practice pattern (i.e. 20 balls randomly drawn at 50 km/h each), prior to and immediately after either mentally demanding tasks (MDT; $n = 11$; continuous Vienna Test System's Stroop task and determination test), physically demanding tasks (PDT; $n = 11$; consisted of 4×4 min of football-specific high-intensity intervals with 3 min of active recovery in between) or a control condition (CON; $n = 11$). Continuous heart rates (HR) as well as self-perceptions of fatigue were assessed. Main findings revealed performances for speed of action ($p = 0.44$; $f = 0.01$) and ball control ($p = 0.15$; $f = 0.03$) that were not modulated in the face of induced physical and mental strain as indicated by increased HR following PDT ($p < 0.001$; $d > 0.8$), or in the face of increased self-perceptions of fatigue following PDT and MDT (both $p < 0.001$; both $d > 0.8$) compared to CON. This is in line with a suggested talent factor and previous reports on motivational trade-off aspects in youth players. However, the present study's short-timed practice patterns make it difficult to reliably compare a measuring sensitivity to complex football-specific movement behavioural and technical proficiencies with respect to mental and physical strain of longer-lasting football games and, thus, need further investigation in favour of improving talent identification and development using the Footbonaut.

Keywords

Coaching · Training · Soccer · Fatigue · Talent development

Fußballtraining mit Nachwuchsspielern im „Footbonaut". Handlungsschnelligkeit und Ballkontrolle unter physischer und mentaler Beanspruchung

Zusammenfassung

Heutzutage ermöglichen modernste leistungsdiagnostische Systeme wie der „Footbonaut" in führenden Fußballtrainingszentren die kontrollierte und standardisierte Beurteilung physischer und mentaler Komponenten der Wendigkeit und Aufgewecktheit, z. B. Handlungsschnelligkeit und Ballkontrolle, die als entscheidend für die Talenterkennung und -entwicklung gelten. Jedoch bleiben die Auswirkungen induzierter physischer und mentaler Belastungen in der Umsetzung fußballspezifischer Übungsformen unklar, insbesondere bei Nachwuchsspielern. Dies zu untersuchen ist das Ziel der vorliegenden Studie. So führten 33 zufällig zugewiesene Nachwuchsfußballspieler (U14 bis U16) standardisierte Footbonaut-Übungsformen aus (d. h., 20 zufällig ausgegebene Bälle, jeweils mit einer Geschwindigkeit von 50 km/h), vor und direkt nach entweder mental fordernden Aufgaben ($n = 11$; „mental demanding tasks", MDT; fortlaufender Stroop-Test gemäß dem Wiener Testsystem), physisch fordernden Aufgaben ($n = 11$; „physically demanding tasks", PDT; bestehend aus 4×4 min fußballspezifischen Intervallen hoher Intensität mit 3 min aktiver Erholung dazwischen) oder einer Kontrollbedingung ($n = 11$; „control condition", CON). Fortlaufend wurden die Herzfrequenz (HF) sowie die selbst wahrgenommene Beanspruchung gemessen. Als zentrale Erkenntnisse zeigten die Handlungsschnelligkeit ($p = 0{,}44$; $f = 0{,}01$) und die Ballkontrolle ($p = 0{,}15$; $f = 0{,}03$) keine Veränderungen durch eine induzierte physische oder mentale Belastung, welche sich in einer erhöhten HF nach PDT ($p < 0{,}001$; $d > 0{,}8$) oder einer erhöhten selbst wahrgenommenen Beanspruchung nach PDT und MDT (beide $p < 0{,}001$; beide $d > 0{,}8$) verglichen mit CON ausdrückte. Dies ist in Einklang mit einem naheliegenden Talentfaktor und vorangegangenen Berichten zu motivationalen Wechselwirkungsaspekten bei Nachwuchsspielern. Allerdings erschweren die zeitlich kurzen Übungsformen der vorliegenden Studie einen verlässlichen Vergleich hinsichtlich der Messsensitivität für verhaltensbezogene und technische Leistungen bei komplexen fußballspezifischen Bewegungen in Bezug auf mentale und physische Beanspruchungen in länger dauernden Fußballspielen. Somit werden weitere Untersuchungen zugunsten einer Verbesserung der Talenterkennung und -entwicklung unter Verwendung des Footbonaut benötigt.

Schlüsselwörter

Coaching · Training · Fußball · Erschöpfung · Talententwicklung

the Footbonaut) after having finished the PDT intervention.

Heart rates (HR) were consistently monitored and recorded after each interval. Monitoring HR served as a control to target 90 to 95% of the maximum HR (HR_{max}) in accordance with previously measured HR during the Yo-Yo intermittent recovery test. If necessary, participants were verbally encouraged to meet the targeted HR prior to finishing the final course interval.

Mentally demanding task (MDT)

Participants of the MDT group were asked to complete a 10-min incongruent Stroop colour-word task that was immediately followed by a 10-min determination test (i.e. S2 version; Neuwirth, & Benesch, 2006). Both tasks were completed using the Vienna Test System (Schuhfried GmbH, Moedling, Austria). Further, a competitive environment was created, to increase motivation, whereby

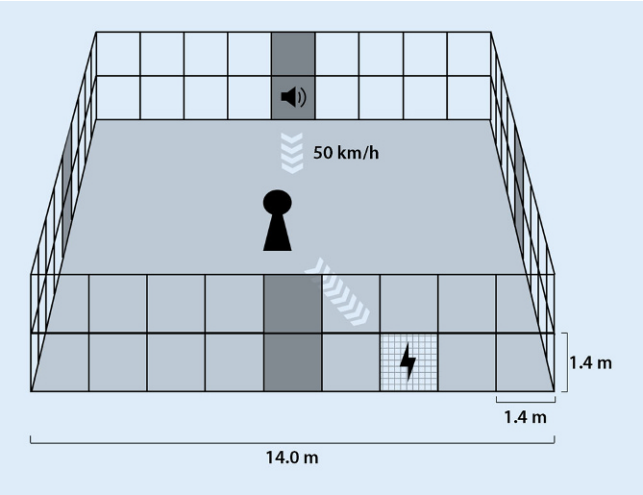

Fig. 1 ▲ Schematic view of the Footbonaut with ball-throwing machines (*dark grey squares*). Each ball was drawn at 50 km/h at ground level subsequent to a beep sound indicating the balls' origin (*sound icon*). Participants (*black character*) had to control and pass each ball (*white arrows* indicate directions) to a lit target (*grid square with lighting icon*) as accurately and quickly as possible

participants were challenged to reach higher scores than the other players of the MDT group. Recently, the Stroop task has successfully been used to induce mental fatigue in similar studies (Badin et al., 2016; Smith et al., 2016a, 2016b, 2017). To prevent participants from being distracted (e.g. practicability in youth players), a shorter duration was chosen and the determination test that had previously been reported to assess stress tolerance causing signs of mental fatigue was added (Hao Ong, 2015; Ishaque, Shamseer, Bukutu, & Vohra, 2012; Olsson, Scheele, & Panossian, 2009).

Control condition (CON)

Participants of the CON group were asked to relax in a separate room, where they were instructed to watch non-arousing football highlights on television, read from magazines or talk to other participants, but not being physically active or being aware of unusual and arousing mental tasks.

Measurements

Heart rate (HR)

Portable standard heart rate monitors (Polar Electro Oy, Finland) were worn throughout the whole study to continuously record heart rates. Peak (baseline, warm-up, Footbonaut-1, Footbonaut-2) and averaged (PDT, MDT, CON) values were exported for statistical analysis.

Self-perception of fatigue

Visual analogue scales (VAS) were used to assess the participants' self-perception of fatigue. Participants were asked to mark self-perception on a 10-cm line, anchored from "not at all" to "totally" fatigued (Badin et al., 2016; Salam, Marcora, & Hopker, 2018; Smith et al., 2016a; Smith et al., 2016b; Smith et al., 2017), before and immediately after interventions (PDT, MDT) or CON. Accordingly, percentaged values were exported for statistical analysis.

Speed of action

Speed of action (seconds) was measured using standardized Footbonaut algorithms, referring to light barriers in the panels of the ball-throwing machines (start timing) and the target panels (stop timing). Speed of action was computed as

$$\text{Speed of action} = (t_{ball(1)} + t_{ball(2)} + \ldots t_{ball(n)})/_{(n)}\text{balls}$$

Computed individual values served for statistical analysis.

Ball control

Ball control (percentaged passing accuracy) was measured using standardized Footbonaut algorithms, referring to a ratio between balls passed correctly (i.e. hit the target) and balls played (i.e. total number). The score for ball control was computed as

$$\text{Score} = \text{Correct passes}_{(n)}/\text{Total passes}_{(n)}$$

Computed individual values served for statistical analysis.

Statistical analyses

Statistical analyses were computed using STATISTICA programme 7.1 (StatSoft, Tulsa, USA).

Repeated measures analysis of variance (ANOVA) was computed to display interactions and main effects for heart rates (bpm), self-perception of fatigue (%), speed of action ($sec_{(ln)}$) and ball control ($score_{(ln)}$), each for factors time (baseline, warm-up, Footbonaut-1, intervention/control condition, Footbonaut-2), group (PDT, MDT, CON) and position (striker, midfielder, defender, goalkeeper), computing intervention-induced effect sizes post-hoc (Cohen, 1977, 1988). Intending to test reliability of the Footbonaut's speed of action and ball control assessments, although Footbonaut-1 and Footbonaut-2 had to be performed on the same day, coefficient of variance (CV, %) and intraclass correlation coefficient (ICC) were computed for CON.

Values for speed of action and ball control were applied to natural logarithm to limit individual variances (Vogt, Abeln, Strüder, & Schneider, 2014). Data in the figures are presented as mean with confidence intervals (95% CI) and in the tables as mean ± standard deviation (SD). The level of significance was set at $p < 0.05$.

Results

Physical and mental strain

Heart rate

The analysis for mean heart rates showed a significant interaction between factors time, group and position ($F_{(24, 84)} = 2.36$, $p < 0.01$; $f > 0.4$); main effects were significant for time ($F_{(4, 84)} = 757.44$, $p < 0.001$; $f > 0.4$) and group ($F_{(2, 21)} = 42.23$, $p < 0.001$;

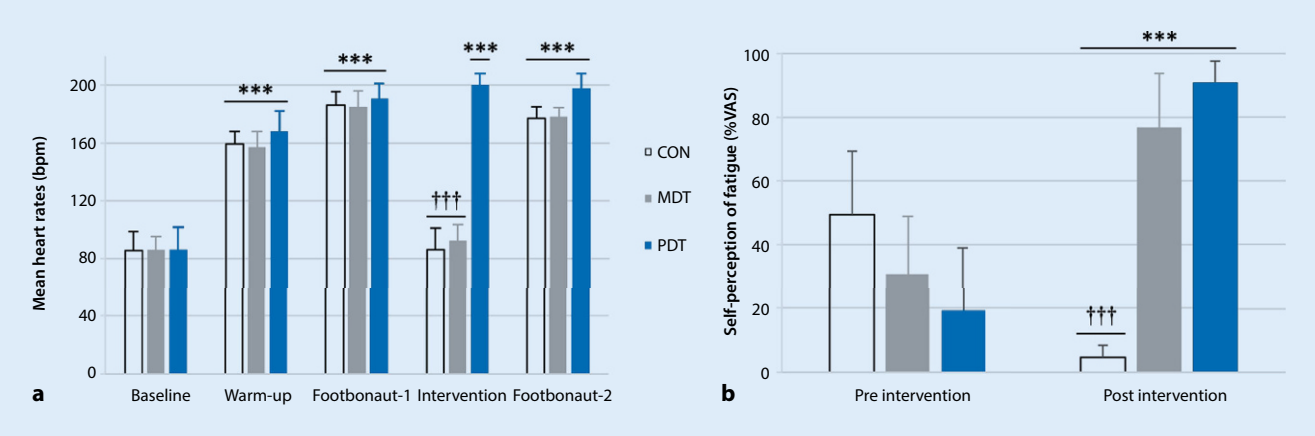

Fig. 2 ▲ In **a** heart rates (bpm) are displayed over time according to mean values with confidence intervals (95%) measured prior to the start of the experiment (baseline) as well as subsequent to a warm-up, the first football-specific practice pattern (Footbonaut-1), the intervention and the second football-specific practice pattern (Footbonaut-2). In **b** percentaged self-perceptions of fatigue based on visual analogue scaling (VAS) are displayed according to mean values with confidence intervals (95%) assessed prior to (pre) and after (post) the intervention. Interventions are labelled as *PDT* (physically demanding task, *blue bars*), *MDT* (mentally demanding task, *grey bars*) and *CON* (*transparent bars*) for the control condition. *Asterisks* (*** for $p < 0.001$) mark significant changes to baseline (in **a**) and pre (in **b**); *crosses* (††† for $p < 0.001$) mark significant changes between the interventions and the control condition

$f > 0.25$), however, not for position ($F_{(3,\ 21)} = 1.42$, $p = 0.26$; $f > 0.4$). Post-hoc tests revealed consecutive increases in heart rate that were halted subsequent to the MDT intervention and CON (**Fig. 2a**).

Self-perception of fatigue

The analysis for a percentaged self-perception of fatigue showed no interaction between factors time, group and position ($F_{(6,\ 21)} = 0.37$, $p = 0.89$; $f > 0.4$); main effects were significant for time ($F_{(1,\ 21)} = 24.45$, $p < 0.001$; $f > 0.25$) and group ($F_{(2,\ 21)} = 21.67$, $p < 0.001$; $f > 0.1$), however, not for position ($F_{(3,\ 21)} = 0.35$, $p = 0.79$; $f > 0.25$). Post-hoc tests on a significant interaction between factors time and group ($F_{(2,\ 21)} = 37.12$, $p < 0.001$; $f > 0.4$) revealed increases for a self-perception of fatigue subsequent to the PDT and MDT intervention, whereas this was reversed subsequent to CON (**Fig. 2b**).

Footbonaut

High degrees of reliability were found for speed of action (ICC 0.80 with CI from 0.24 to 0.95, $F_{(10,\ 10)} = 4.71$, $p < 0.5$; CV 4.61%) and ball control (ICC 0.70 with CI from −0.21 to 0.921, $F_{(10,\ 10)} = 3.13$, $p < 0.05$; CV 2.53%) in CON.

Speed of action

The analysis for speed of action (**Table 1**) showed no interaction between factors time, group and position ($F_{(6,\ 21)} = 1.01$, $p = 0.44$; $f = 0.01$); the main effect was significant for time ($F_{(1,\ 21)} = 6.55$, $p < 0.05$; $f > 0.4$), however, not for group ($F_{(2,\ 21)} = 0.17$, $p = 0.85$; $f > 0.4$) and position ($F_{(3,\ 21)} = 1.51$, $p = 0.24$; $f > 0.4$).

Ball control

The analysis for ball control (**Table 1**) showed no interaction between factors time, group and position ($F_{(6,\ 21)} = 1.10$, $p = 0.39$; $f = 0.03$); main effects were not significant for time ($F_{(1,\ 21)} = 2.25$, $p = 0.15$; $f > 0.4$), group ($F_{(2,\ 21)} = 0.13$, $p = 0.88$; $f > 0.4$) and position ($F_{(3,\ 21)} = 1.54$, $p = 0.23$; $f > 0.4$).

Discussion

This study aimed to examine football-specific speed of action and ball control in U14 to U16 youth players, comparing signs of mental and physical fatigue to a control condition. The test was performed according to standardized practice patterns of the Footbonaut as a state-of-the-art performance diagnostic system for talent identification and development. Main findings revealed increased HR following PDT compared to CON as well as increased self-perceptions of fatigue following PDT and MDT compared to CON; however, speed of action and ball control performances were not modulated by mental or physical strain.

According to our initial first hypothesis of inducing signs of physical and mental fatigue in youth football players, the prescribed interventions (PDT, MDT) generated physical and mental strain as expected. Compared to baseline, the physiological activation (e.g. increase in acute HR) following the present study's warm-up procedure (similar increases in acute HR for PDT, MDT and CON) and, more importantly, continuing after PDT compared to MDT and CON, is in line with previous research using football-specific (small-sided football fields) or 4 × 4 HIT intervals in youth football players to increase, for example, acute HR (Faude, Steffen, Kellmann, & Meyer, 2014; Selmi et al., 2017; Wiewelhove et al., 2016). The decreased HR indicative of a minor physiological activation following MDT (and also CON) compared to previous measurements (baseline, warm-up procedure, Footbonaut-1) and, more importantly, compared to PDT, supports an inducing of the prescribed different signs of fatigue in the present study (e.g. physical, mental). This is underlined by an increase in the self-perception of fa-

Table 1 Speed of action and ball control

		Speed of action, (ln)sec	Ball control, (ln)score
	***n* = 33**	**pre mean 0.94 ± SD 0.08 post mean 0.91 ± SD 0.12**	**pre mean 4.24 ± SD 0.21 post mean 4.28 ± SD 0.17**
Intervention	CON (*n* = 11)	0.96 ± 0.08 0.94 ± 0.11	4.20 ± 0.21 4.20 ± 0.18
	MDT (*n* = 11)	0.93 ± 0.08 0.88 ± 0.15	4.29 ± 0.19 4.32 ± 0.15
	PDT (*n* = 11)	0.92 ± 0.08 0.91 ± 0.11	4.25 ± 0.24 4.33 ± 0.14
Position	Striker (*n* = 4)	1.04 ± 0.04 0.95 ± 0.07	4.07 ± 0.25 4.13 ± 0.15
	Midfielder (*n* = 16)	0.92 ± 0.07 0.94 ± 0.12	4.25 ± 0.18 4.28 ± 0.16
	Defender (*n* = 9)	0.94 ± 0.07 0.88 ± 0.15	4.29 ± 0.27 4.33 ± 0.18
	Goalkeeper (*n* = 4)	0.92 ± 0.04 0.85 ± 0.12	4.32 ± 0.05 4.38 ± 0.05

Interventions are labelled as control condition (CON), physically demanding task (PDT) and mentally demanding task (MDT)

tigue following MDT but not CON despite decreased HR indicative of a minor physiological activation and, thus, physical strain following MDT and CON. However, this indicates signs of mental fatigue following MDT. MDT consisted of the well-established Stroop task (Smith et al., 2016a, b, 2017). In order to avoid possible distraction and lack of attention, a shorter version of the Stroop task was used and, instead, aligned with an additional determination test. The combination of this shortened Stroop task and determination test has served to induce mental strain and, thus, signs of mental fatigue in youth football players.

Interestingly, neither physical nor mental signs of fatigue modulated speed of action or ball control performed in accordance with standardized practice patterns of the Footbonaut. Although revealing a learning effect for speed of action (participants performed in the Footbonaut for the first time; ICC 0.80), these findings contradict our leading second hypothesis of impaired speed of action and ball control following physical and mental strain in youth football players (also with respect to their assigned classical positions on the football field, e.g. striker, midfielder, defender, goalkeeper).

Against plausible coaches' argumentations and previous research reporting on reduced sports performances as a result of fatigue (Knicker et al., 2011), there is evidence supporting the present study's findings on succeeding performances of speed of action despite induced physical and mental strain, in particular with respect to young athletes and more specifically youth football players. For example, Reilly, Williams, and Franks (2000b) discuss a talent factor that suggests more talent in youth football players to be accompanied with greater resistance against fatigue due to greater technical skills. Additionally, more talent has been associated with physical stamina (Reilly, Bangsbo, & Franks, 2000a). With respect to this, it seems reasonable that the present study's participants—who were recruited from competitive youth football level and, thus, may be considered as talented youth football players—succeeded in their speed of action performances, at least with respect to PDT. For speed of action with respect to MDT, environmental stimuli have been taken into account (Smith et al., 2016b). Smith et al. (2016b) suggest signs of mental fatigue that may negatively affect football-specific speed of action to result from possible restricted abilities to classify environmental distractions, e.g. cheering or booing supporters that may add to a perceived mental strain. Taking the present study's Footbonaut setup into account (shielded "ball cage"), it seems reasonable that the participating youth football players were less or even not at all distracted by environmental stimuli. In fact, the Footbonaut setup may be considered to allow for a strict attention focus on the acoustic and visual stimuli necessary in order to perform at the participants' best abilities (e.g. speed of action), and this may be irrespective of induced mental strain. Moreover, motivation has been shown to improve when performing in competitive situations, resulting in improved performances (Lazarus, 2000). Therefore, individually performing while knowingly being measured and, thus, competing with team mates may have served to enhance motivational states. Following this line of thought, it seems reasonable that the Footbonaut, as a state-of-the-art performance diagnostic system, generated additional motivation in the present study's youth football players that may have helped to counteract the induced mental strain and eventually succeed in speed of action performances.

According to ball control performances that were also not modulated by induced physical or mental strain, Rampinini et al. (2009) report that physical strain may negatively affect technical skills, thus, including ball control. However, this relates to the number of intense actions within, mostly, later parts of a football game (Rampinini et al., 2009), rather than the present study's possibly intense but short-term Footbonaut practice patterns (e.g. 20 balls). Further, and similar to speed of action performances, unaffected ball control performances need to take motivational aspects into consideration (Lazarus, 2000). With respect to possible trade-offs (Smith et al., 2017), a negative effect of induced mental strain in disfavour of passing accuracy (e.g. ball control; Smith et al., 2017) may have been counteracted by the participants' motivation to eventually succeed in ball control performances in the Footbonaut following MDT.

However, in addition to a plausible talent factor and motivational trade-off aspects, todays' missing—if not club-internal confidential and, thus, unpublished—evidence from Footbonaut research makes it difficult to exclude a reasonable doubt on the Footbonaut

being a sensitive and therefore suitable scientific measuring device itself (e.g. learning effect, intensity, combination effects), in particular with respect to transferred signs of physical and mental fatigue affecting football-specific movement behavioural and technical proficiencies (Badin et al., 2016; Boksem et al., 2006; Smith et al., 2016a). Moreover, and irrespective of a successful application in leading training centres of professional football clubs, the present study's findings on succeeding performances for speed of action and ball control resulting from short-timed practice patterns in the Footbonaut (i.e., 20 balls played compared to a 90- or even 120-minute football game) need to be considered carefully with respect to previous reports on signs of fatigue setting in towards the final stages of, for example, football games (Rampinini et al., 2009, 2008).

Limitations

We are well aware that the present study's findings are subject to limitations: despite considerable familiarization of the participants in the Footbonaut, it cannot be excluded that unfamiliar and rather short-timed practice patterns (i.e. 20 balls played) may have influenced the participant's performance and, thus, the Footbonaut's outcome for speed of action and ball control. According to plausible effects of motivation, additional assessments on the participant's motivational state relative to Footbonaut performances may need consideration for future research, as well as better controlling for possible effects on HR that may be caused by excitement or unpredictability (e.g. caused by an unfamiliar nature of the Footbonaut's signalling and drawing the to-be-played balls). If reconcilable with the respective procedures onsite (i.e. collaborating Bundesliga training centre), time-consuming but valuable repeated baseline measurements as well as additional parameters may also strengthen the assessment of physical and mental strain (e.g. cortisol level, lactate concentration). However, all measured parameters clearly indicated the preconditioned interventions and, thus, served the practical approach of the present study. Last but not least, despite robust, if not profound (i.e. CV findings), as well as reasonable reliability (i.e. ICC findings in CON participants that had not been subjected to interventions of physical or mental strain), the intended compensation for reliability testing based on same-day performances as well as the number of participants itself may limit the present study's findings. This, however, faces the challenge of recruiting (more) competitive youth football players to volunteer in a scientific study that had to run on a tightly synchronised schedule in the pre-season and, at the same time, does not interfere with daily (prioritised) measuring procedures of a German Bundesliga club in its training centre.

Conclusion

In conclusion, the present study aimed to examine football-specific speed of action and ball control assessed in the Footbonaut and performed by U14 to U16 youth players when exposed to signs of mental and physical fatigue. In addition to a learning effect that likely results from previously unfamiliar Footbonaut practice patterns, speed of action and ball control were generally not modulated but succeeded despite the induced mental and physical strain, which is in line with a suggested talent factor (Reilly et al., 2000b) as well as possible trade-offs resulting from additionally generated motivation (Smith et al., 2017). However, the present study's succeeding performances for speed of action and ball control in U14 to U16 youth players need to be considered carefully with respect to their assessment using short-timed practice patterns, which thus makes it difficult to reliably compare the potential sensitivity of the Footbonaut to 90- or even 120-min football games, particularly according to complex football-specific movement behavioural and technical proficiencies. Therefore, future research may take the great variety of Footbonaut practice patterns into account to further and eventually establish scientific evidence, helping to improve talent identification and development in youth and professional football.

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Acknowledgements. The authors would like to extend their sincere gratitude to all youth football talents for spending some of their valuable pre-season practice time to participate in the study. We further wish to thank the TSG 1899 Hoffenheim for enabling us to test in the Footbonaut and for providing supportive staff members during data collection.

Compliance with ethical guidelines

Conflict of interest. T. Vogt, S. Gassen, S. Wrede, J. Spielmann, M. Jedrusiak-Jung, S. Härtel and J. Mayer declare that they have no competing interests.

All participants and their legal guardians provided written informed consent. The study was approved by the Human Research Ethics Committee of the German Sport University Cologne in compliance with the Declaration of Helsinki.

References

Ackerman, P. L. (2011). 100 years without resting. In P. L. Ackerman (Ed.), *Cognitive fatigue: multidisciplinary perspectives on current research and future applications* (pp. 11–43). Washington: American Psychological Association.

Badin, O. O., Smith, M. R., Conte, D., & Coutts, A. J. (2016). Mental fatigue: impairment of technical performance in small-sided soccer games. *International journal of sports physiology and performance*, *11*(8), 1100–1105.

Bangsbo, J., Madsen, K., Kiens, B., & Richter, E. A. (1996). Effect of muscle acidity on muscle metabolism and fatigue during intense exercise in man. *The Journal of physiology*, *495*(2), 587–596.

Bisanz, G., & Gerisch, G. (2008). *Fußball: Kondition-Technik-Taktik und Coaching*. Aachen: Meyer + Meyer Fachverlag.

Boksem, M. A., & Tops, M. (2008). Mental fatigue: costs and benefits. *Brain research reviews*, *59*(1), 125–139.

Boksem, M. A., Meijman, T. F., & Lorist, M. M. (2006). Mental fatigue, motivation and action monitoring. *Biological psychology*, *72*(2), 123–132.

Bradley, P. S., Sheldon, W., Wooster, B., Olsen, P., Boanas, P., & Krustrup, P. (2009). High-intensity running in English FA Premier League soccer matches. *Journal of sports sciences*, *27*(2), 159–168.

Bradley, P. S., Di Mascio, M., Peart, D., Olsen, P., & Sheldon, B. (2010). High-intensity activity profiles of elite soccer players at different performance levels. *The journal of strength & conditioning research*, *24*(9), 2343–2351.

Castagna, C., Impellizzeri, F. M., Rampinini, E., D'Ottavio, S., & Manzi, V. (2008). The Yo-Yo intermittent recovery test in basketball players. *Journal of science and medicine in sport*, *11*(2), 202–208.

Cohen, J. (1977). *Statistical power analysis for the behavioral sciences*. Hillsdale: Erlbaum.

Cohen, J. (1988). *Statistical power analysis for the behavioural sciences*. Hillsdale: Erlbaum.

Van Cutsem, J., Marcora, S., De Pauw, K., Bailey, S., Meeusen, R., & Roelands, B. (2017). The effects of mental fatigue on physical performance: a systematic review. *Sports medicine*, 1–20. https://doi.org/10.1007/s40279-016-0672-0.

Faude, O., Steffen, A., Kellmann, M., & Meyer, T. (2014). The effect of short-term interval training during the competitive season on physical fitness and signs of fatigue: a crossover trial in high-level youth football players. *International journal of sports physiology and performance*, *9*(6), 936–944.

Fitts, R. H. (2006). The muscular system: fatigue processes. In *ACSM's advanced exercise physiology* (pp. 178–196).

Hao Ong, N. C. (2015). The use of the Vienna Test System in sport psychology research: a review. *International review of sport and exercise psychology*, *8*(1), 204–233.

Hohmann, A., Lames, M., & Letzelter, M. (2002). *Einführung in die Trainingswissenschaft*. Wiebelsheim: Limpert.

Hyballa, P., & te Poel, H. D. (2015). *Modernes Passspiel: Der Schlüssel zum High-Speed-Fußball*. Aachen: Meyer & Meyer.

Ishaque, S., Shamseer, L., Bukutu, C., & Vohra, S. (2012). Rhodio rosea for physical and mental fatigue: a systematic review. *BMC complementary and alternative medicine*, *12*, 70.

Knicker, A. J., Renshaw, I., Oldham, A. R., & Cairns, S. P. (2011). Interactive processes link the multiple symptoms of fatigue in sport competition. *Sports medicine*, *41*(4), 307–328.

Krause, K., Kärcher, M., Munz, O., & Brack, R. (2012). Perspektiven und Einflussfaktoren erfolgreicher Nachwuchsförderung im Fußball – eine Analyse der Innen- und Außensicht. *Leistungssport*, *42*(4), 34–39.

Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A., & Bangsbo, J. (2003). The yo-yo intermittent recovery test: physiological response, reliability, and validity. *Medicine & science in sports & exercise*, *35*(4), 697–705.

Krustrup, P., Mohr, M., Steensberg, A., Bencke, J., Kjær, M., & Bangsbo, J. (2006). Muscle and blood metabolites during a soccer game: implications for sprint performance. *Medicine & science in sports & exercise*, *38*(6), 1165–1174.

Lazarus, R. S. (2000). How emotions influence performance in competitive sports. *The sport psychologist*, *14*(3), 229–252.

Marcora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of applied physiology*, *106*(3), 857–864.

Michailidis, Y., Michailidis, C., & Primpa, E. (2013). Analysis of goals scored in European Championship 2012. *Journal of human sport & exercise*, *8*, 367–375.

Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of sports sciences*, *21*(7), 519–528.

Nédélec, M., McCall, A., Carling, C., Legall, F., Berthoin, S., & Dupont, G. (2012). Recovery in soccer: part I-post-match fatigue and time course of recovery. *Sports medicine*, *42*, 997–1015.

Neuwirth, W., & Benesch, M. (2006). *Vienna test system. Determination test*. Mödling: Schuhfried.

Noakes, T. D., & Gibson, A. S. C. (2004). Logical limitations to the "catastrophe" models of fatigue during exercise in humans. *British journal of sports medicine*, *38*(5), 648–649.

Olsen, E. (1986). An analysis of goal scoring strategies in the world championship in Mexico. In T. Reilly, A. Lees & W. Murphy (Eds.), *Science and football* (pp. 373–376). London: E & FN Spon.

Olsson, E. M., von Scheele, B., & Panossian, A. G. (2009). A randomised, double-blind, placebo-controlled, parallel-group study of the standardised extract shr-5 of the roots of Rhodiola rosea in the treatment of subjects with stress-related fatigue. *Planta medica*, *75*(2), 105–112.

Rampinini, E., Impellizzeri, F. M., Castagna, C., Abt, G., Chamari, K., Sassi, A., & Marco-ra, S. M. (2007). Factors influencing physiological responses to small-sided soccer games. *Journal of sports sciences*, *25*(6), 659–666.

Rampinini, E., Impellizzeri, F. M., Castagna, C., Azzalin, A., Ferrari Bravo, D., & Wisløff, U. (2008). Effect of match-related fatigue on short-passing ability in young soccer players. *Medicine and science in sports and exercise*, *40*(5), 934–942.

Rampinini, E., Impellizzeri, F. M., Castagna, C., Coutts, A. J., & Wisløff, U. (2009). Technical performance during soccer matches of the Italian serie A league: effect of fatigue and competitive level. *Journal of science and medicine in sport*, *12*(1), 227–233.

Reilly, T., Bangsbo, J., & Franks, A. (2000a). Anthropometric and physiological predispositions for elite soccer. *Journal of sports sciences*, *18*(9), 669–683.

Reilly, T., Williams, A. M., & Franks, A. (2000b). A multidisciplinary approach to talent identifiction in soccer. *Journal of sport sciences*, *18*(9), 695–702.

Saal, C., Zinner, J., Büsch, D., Werner, C., & Ückert, S. (2013). Der Footbonaut als Mess- und Informationssystem im Sportspiel Fußball. *Zeitschrift für Gesundheit & Sport*, *1*(3), 54–61.

Saal, C., & Fiedler, H. (2013). Der Footbonaut als Mess- und Informationssystem im Fußball – Eine explorative Untersuchung. Poster auf der Jahrestagung der dvs-Kommission Fußball, Technische Universität München, 14(16.11).

Sajadi, N., & Rahnama, N. (2007). Analysis of goals in 2006 FIFA World Cup. *Journal of sports science and medicine*, *6*, 3.

Salam, H., Marcora, S. M., & Hopker, J. G. (2018). The effect of mental fatigue on critical power during cycling exercise. *European journal of applied physiology*, *118*, 85–92.

Schnabel, G. (2008). *Trainingslehre-Trainingswissenschaft: Leistung-Training-Wettkampf*. Aachen: Meyer & Meyer.

Selmi, O., Haddad, M., Majed, L., Ben, K. W., Hamza, M., & Chamari, K. (2017). Soccer training: high-intensity interval training is mood disturbing while small sided games ensure mood balance. *The Journal of sports medicine and physical fitness*. https://doi.org/10.23736/S0022-4707.17.07292-9.

Smith, M. R., Coutts, A. J., Merlini, M., Deprez, D., Lenoir, M., & Marcora, S. M. (2016a). Mental fatigue impairs soccer-specific physical and technical performance. *Medicine & science in sports & exercise*, *48*(2), 267–276.

Smith, M. R., Zeuwts, L., Lenoir, M., Hens, N., De Jong, L. M., & Coutts, A. J. (2016b). Mental fatigue impairs soccer-specific decision-making skill. *Journal of sports sciences*, *34*(14), 1297–1304.

Smith, M. R., Fransen, J., Deprez, D., Lenoir, M., & Coutts, A. J. (2017). Impact of mental fatigue on speed and accuracy components of soccer-specific skills. *Science and medicine in football*, *1*(1), 48–52.

Vogt, T., Abeln, V., Strüder, H. K., & Schneider, S. (2014). Artificial gravity exposure impairs exercise-related neurophysiological benefits. *Physiology & behavior*, *123*(2014), 156–161.

Walsh, V. (2014). Is sport the brain's biggest challenge? *Current Biology*, *24*, R859–R860.

Weineck, J. (2004). *Optimales Fußballtraining. Das Konditionstraining des Fußballspielers* (4th edn.). Balingen: Spitta.

Westerblad, H., Allen, D. G., & Lännergren, J. (2002). Muscle fatigue: lactic acid or inorganic phosphate the major cause? *Physiology*, *17*(1), 17–21.

Wiewelhove, T., Fernandez-Fernandez, J., Raeder, C., Kappenstein, J., Meyer, T., Kellmann, M., & Ferrauti, A. (2016). Acute responses and muscle damage in different high-intensity interval running protocols. *The journal of sports medicine and physical fitness*, *56*(5), 606–615.