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Summary

In this article, we introduce positioning systems in combination with innovative data processing approaches for estimating external loads and internal demands during intermittent running activities in team and racquet sports. Potential application fields are (i) performance analyses for profiling athletes; (ii) training analyses for allowing periodizations; and (iii) rehabilitative analyses for supporting return to play/competition decisions. Technological prerequisites are the (i) selection of an appropriate technology for which knowledge concerning the technical background is essential; and (ii) application of filtering techniques for eliminating noise. Using positioning system derived velocity and chest-belt measured heart rate data as inputs, innovative data processing approaches allow to estimate the (i) mechanical power and concentric/eccentric movement phases during changes of direction; (ii) metabolic power, mechanical efficiency, energy expenditure, and amount of aerobic/anaerobic energy supply; and (iii) stroke volume and cardiac output. Future perspectives are to develop positioning systems for (i) jump; (ii) technical–tactical skill; and (iii) movement analyses as well as (iv) to integrate biosensor data into the presented approaches for increasing their validity.

Keywords
GPS – Handball – Player tracking technology – Soccer – Tennis

REVIEW / SPECIAL ISSUE

Estimating external loads and internal demands by positioning systems and innovative data processing approaches during intermittent running activities in team and racquet sports

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Introduction

In team and racquet sports, fundamental characteristics of the activity profile are intermittent running activities, containing repeated accelerations, decelerations, sprints, and changes of direction [40,69]. Regarding external loads (e.g., forces) [63] and internal demands (e.g., metabolism) [12], intermittent running activities are less investigated; especially under field conditions, involving more sport-specific open skill [73] and fatigue/pacing [60] situations compared to laboratory conditions [79]. Plausibly, this lack of research is due to the fact that no appropriate technologies were available in the past.

However, in this article, we introduce positioning systems, as a state of the art technology in sport science, in combination with innovative data processing approaches for estimating external loads and internal demands during intermittent running activities. Fig. 1 shows the flow-chart of our article and summarizes the key points of each section. First, application fields of positioning systems in team and racquet sports are suggested. Then, technological prerequisites, namely the selection of an appropriate technology and application of filtering techniques, are explained. Next, innovative data processing approaches for estimating external loads and internal demands

Abbreviations: a, acceleration; ACC/DEC, acceleration/deceleration; arctan, arctangent; $(a\text{-}v)O_2$, arterial-venous oxygen difference; CI, confidence interval; CO, cardiac output; COD, change of direction; CON, concentric; EC, energy cost; ECC, eccentric; EE, energy expenditure; ES, equivalent slope; F_{aero}, aerodynamic drag force; g, acceleration due to gravity; GPS, global positioning system; h, body height; HR, heart rate; KT, terrain constant (i.e., 1.29 for grass); LPS, local positioning system; m, body mass; p_b, barometric pressure; P_{mech}, mechanical power; P_{met}, metabolic power; SV, stroke volume; t, time; T, air temperature; tan, tangent; TEE, typical error of estimate; v, velocity; v_{max}, theoretical maximal running velocity reached at the end of the acceleration phase; VO_2, oxygen uptake; VO_2T, theoretical VO_2 at each P_{met} value; v_W, wind velocity; τ, acceleration time constant

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Modellierung der externen Belastungen und inneren Beanspruchungen mittels Ortungssystemen und innovativen Datenanalysen während intervallartiger Laufaktivitäten in den Mannschafts- und Rückschlagsportarten

Zusammenfassung

In diesem Artikel werden Ortungssysteme und innovative Datenanalysen für die Modellierung der externen Belastungen und inneren Beanspruchungen während intervallartiger Laufaktivitäten in den Mannschafts- und Rückschlagsportarten vorgestellt. Zu den möglichen Anwendungsfeldern gehören (i) Leistungsdiagnostiken sowie Analysen des (ii) Trainings und (iii) Rehabilitationsverlaufs. Zwei wichtige technische Voraussetzungen für den Einsatz sind die (i) Auswahl einer geeigneten Technologie und (ii) Anwendung von Filtertechniken. Auf Grundlage der gemessenen Geschwindigkeits- und Herzfrequenzdaten ermöglichen innovative Datenanalysen die Modellierung (i) der mechanischen Leistung und konzentrischen/exzentrischen Muskelarbeit während Richtungswechseln, (ii) der metabolischen Leistung, des Wirkungsgrads, des Energieverbrauchs und der aeroben/anaeroben Energiebereitstellung sowie (iii) des Schlagvolumens und Herzzeitvolumens. Zukünftig sollten Ortungssysteme für die Analysen von (i) Sprüngen, (ii) technisch-taktischen Fertigkeiten und (iii) Bewegungen weiterentwickelt werden. Ferner sollten (iv) Biosensordaten mit in die vorgestellten Ansätze integriert werden, um deren Validität zu verbessern.

Schlüsselwörter
Fußball – GPS – Handball – Positionsbestimmung – Tennis

are emphasized and exemplary outcomes are displayed and discussed. Finally, future perspectives and conclusions are provided.

Application fields

In team and racquet sports, one application field of positioning systems are performance analyses [24], including standardized field tests (e.g., linear, nonlinear, and repeated sprint tests or sport-specific circuits) and match analyses (i.e., friendly and competitive matches). The resulting data (e.g., maximal velocity during sprint tests or total distance covered during play) can be used to profile the athletes, for example, regarding age [19], gender [14], playing position [29], level [16], strategy [46], or success [50]. Such performance profiles can be helpful to design training drills in terms of the particular physical needs to compete [22].

A further application field are training analyses [20]. The obtained data, that can even be analyzed in real-time, can allow, particularly related to performance (e.g., competitive match data) [82] or combined with biochemical measures (e.g., creatine kinase, urea, or microRNAs) [47], a daily periodization [18]. This can assist to optimize recovery and adaptation processes [80], potentially improving the performance [20] and prevention of injuries [39], for instance, in fatigued conditions [43]. Consequently, training analyses can especially be important between frequent matches and during long/intensive training periods.

An overlooked application field are rehabilitative analyses [70]. While standardized laboratory tests (e.g., jump and isokinetic tests) can assist with return to activity/sport decisions, for example, after an anterior cruciate ligament reconstruction, they are potentially not valid enough to also help with return to play/competition decisions [41]. However, after the athletes have returned to sports and perform on-court, for example, individualized drills with reduced external loads [80] or parts of the (team) training [35], longitudinal analyses of the daily rehabilitation process (e.g., related to pre-injury performance profiles) by positioning systems can be useful to assist with return to play/competition decisions [2,70], requiring extensive research.

Selection of an appropriate technology

A prerequisite to use positioning systems for the suggested application fields, is the selection of an appropriate technology for which knowledge concerning the technical background is essential. Briefly, in recent years, the positioning technology has switched away from video-camera to GPS and LPS [48]. Both newer technologies determine the position (i.e., the *x*,*y*-coordinates) by triangulation [3,76]. Therefore, GPS devices use time signals emitted by satellites orbiting the earth (i.e., a "passive-global" measurement) [55], while the LPS functions in the opposite manner [76] such that the devices send time signals to locally placed antennae (i.e., an "active-local" measurement) [74]. When the position and sampling rate are known, the velocity can be computed via positional differentiation (i.e., distance over time) [59]. Noteworthy, latest GPS devices derive the velocity not from positional data, but rather by the Doppler-shift (i.e., from the changes in the time signals) [59].

Compared to the GPS, and due to the different measurement principle, the LPS has three main advantages: (i) more accurately detecting the

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