Universidade de Lisboa

Faculdade de Motricidade Humana

Informational Variables for Basketball Dribble Control

Ricardo André Monteiro Robalo

Orientador: Prof. Doutor Pedro José Madaleno Passos

Tese especialmente elaborada para obtenção do grau de Doutor no Ramo de Motricidade Humana especialidade em Comportamento Motor

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Gostava de vos contar o quão duro foi este processo. Mas a verdade é que duro duro, era não ter acabado.

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"O deixar-me mandar para fora de pé de vez em quando, responsabilizando-me, foi essencial para o meu crescimento enquanto investigador" Robalo (2012)

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Ao Tomás:
Que eu seja metade contigo do que foram comigo.

Table of Contents

Tables and figures

Tables List

Figure List

Equations List

Abbreviations

3D	Three-dimensional
AO	Auditory occlusion
ApEn	Approximate entropy
BO	Both occlusions
COD	Correlation dimension
FIBA	Fédération Internationale de Basketball
LyE	Lyapunov exponent
NO	No occlusion
UCM	Uncontrolled manifold
UCM Down	Synergy value at wrist lowest height
UCM Up	Synergy value at wrist peak height
VO	Peripheral vision occlusion

Abstract

Analyzing the influence of perceptual variables on basketball dribbling motor control can provide precise information on how this kind of control operates. To assess these variables contribution to the motor control process two groups were tested (i.e. amateurs and professionals), with distinct levels of experience under the perceptual occlusion paradigm, in a static dribble task (i.e., no overall displacement of the individual). Auditory and peripheral vision were chosen as the perceptual variables to be occluded for this study because both, often, are constrained in a competitive setup. The main goal of the thesis was identifying how joints adapted their behavior to each of these two occlusions, when presented alone or together, allowing us to establish an adaptive profile for each group. To do so, tools of non-linear (i.e. such as correlation dimension, approximate entropy and Lyapunov exponent), synergistic (i.e. uncontrolled manifold) and dissimilarity analysis (i.e. Procrustes) were used in order to design behavior adaptation profiles for the upper limb main joints when exposed to occlusion phenomena. Overall auditory occlusion had no significant influence in the chosen variables. Even when used jointly with peripheral vision occlusion no cumulative effects in adaptive behavior was observed. However, peripheral vision occlusion lead to some adaptive behaviors throughout both groups that made us conclude the following: 1) wrist position stability is a performance indicator and represents a superior adaptive mechanism; 2) lateral elbow variability and horizontal shoulder variability (i.e. anterior-posterior and lateral) are performance factors allowing the system to be more flexible, thus improving its ability to adapt to constraints; 3) shoulder and elbow angles form a synergy between them in order to stabilize wrist vertical position; 4) the aforementioned synergy is not constant throughout the whole cycle; 5) peripheral vision occlusion disturbs amateurs dribbling performance almost four times more than it does to professionals.

Keywords:

Dribble; Coordination Control; Variability; Synergies; Dissimilarity

Resumo

A análise das variáveis preceptivas para o controlo motor do drible pode fornecer indicadores objetivos sobre o funcionamento deste controlo. Para avaliar a contribuição de cada uma das variáveis testámos dois grupos com níveis de experiências distintos (i.e., amadores e profissionais) sob o paradigma da oclusão numa tarefa de drible estático (i.e., sem deslocamento do individuo). As variáveis percetivas escolhidas foram a visão periférica e a audição devido aos constrangimentos que os atletas encontram frequentemente em ambiente competitivo. O objetivo foi identificarmos as adaptações que a oclusão provoca, separadamente ou em conjunto, num conjunto de variáveis de natureza articular, podendo posteriormente estabelecer um perfil adaptativo para cada um dos grupos de experiência. Usámos ferramentas de análise não-linear (i.e., dimensão correlacionada, entropia aproximada e expoente de Lyapunov), análise de sinergias (i.e., uncontrolled manifold) e análise de dissemelhança (i.e. Procrustes) para traçar um perfil de comportamento das principais articulações do membro superior quando exposta a fenómenos de oclusão. A oclusão da audição não teve influências significativas nas variáveis analisadas, mesmo quando usada juntamente com a oclusão da visão periférica efeitos adaptativos cumulativos não foram observados. No entanto, através dos comportamentos adaptativos provocados pela oclusão da visão periférica várias conclusões emergiram da nossa análise: 1) a estabilidade da posição do punho é um indicador de performance que representa um melhor comportamento adaptativo; 2) a variabilidade da posição lateral do cotovelo e da posição horizontal do ombro (i.e. ântero-posterior e lateral) é um fator de performance e carateriza uma melhor flexibilidade de adaptação aos constrangimentos; 3) o ângulo do ombro e do cotovelo têm um comportamento sinérgico entre si para estabilizar a posição vertical do punho na execução do drible; 4) a sinergia entre o ângulo do ombro e o cotovelo não é constante durante todo o ciclo de execução; 5) a oclusão da visão periférica perturba a performance no drible nos amadores quase quatro vezes mais que o verificado nos profissionais.

Palavras-chave:

Drible; Coordenação Motora; Variabilidade; Sinergia; Dissemelhança

Introduction

The concept of control of human movement has classically been linked to the capacity of the human mind often classified as limited. Analyzing the mind as a computing device would imply that whatever sensory input it received would be acted upon through the execution of a pre-existing motor plan (e.g., see Beek and Meijer, 1988; Abernethy and Sparrow, 1992; Williams et al., 1992; Davids et al., 1994 for comprehensive reviews). Therefore, movement was inherently dependent on previous knowledge and the kinetic execution was just consequence of a motor program stored in the central nervous system (CNS) (Kelso, 1981). For years, this was accepted throughout the scientific community as how movement control happened (Newell, 1985).

This theory started then to be questioned because of the computing-process burden that this might bring to the system. The system had to acknowledge so many constraints that were ever-changing and have so many motor programs stored to meet the environmental demands that, informationally wise would be required an extraordinary fast processor capable of conducting too many computations per second (Handford et al., 1997). This notion of required flexibility caused problems for the traditional information-processing stance on human performance.

Each motor system has an arguably huge number functional possibilities (i.e., angular joint ranges, speeds, accelerations etc.) which provides the system with a multitude of degrees of freedom (DOF) (here analyzed as possibilities of action). This huge number of system capabilities represents a serious challenge to the computational-based theories on skill acquisition and performance (Kugler & Turvey, 1987). Some empirical work data (e.g., Bennett & Davids, 1996; Lacquaniti & Maioli, 1989) gave support for the theoretical rebuttal providing some evidence that, successful performers were able produce different movement patterns in order to adapt to a change in the environmental information, maintaining their degree of success, even though that predictably they would not function under the influence of a super-computer capable of a huge number of computations per second.

Research started to be made trying to find correlations between action and perception, and trying to understand how did constraints acted upon intentional change and skill-learning process. Kelso (2012) argued that multistabilty (i.e. universal, essentialy nonlinear aspect of matter and how it is organized, determining the stability of a system while performing) along with instability, transitions and metastability (i.e. a property that gives the system the ability of not being stable to a point where it cannot adapt to new states, where it cannot find new attractors) gave the system the balance it needed to perform successfully and consistently without losing its ability to adapt.

The dynamical systems theory

From this moment on, dynamical systems theorists rose and argued that perceptual information itself constrained coordinated movements during functional, goal-directed activities. Both the environment and the specific movements being performed formed new perceptual information that is used to guide the neuromuscular system towards the most adaptive pattern towards a successful task execution (Handford et al., 1997).

Since the rise of the dynamical systems theory, variability started to be perceived as more than just noise or error. Technologically advances made possible studies with an increased capacity to track movements trial-to-trial, concluding that movement patterns were intra-individually different with similar performance outcomes strengthening the notion of variability as something inherent within and between biological systems (Davids et al., 2003). Even elite athletes were not able to reproduce identical movement patterns, for the authors it became clear that the dynamics of the system would invariably change for a particular performer under a specific set of task constraints.

Variability

The presence of movement variability was now acknowledged by the scientific community although its role in motor control was not clear yet. Since variability was somehow a feature of high level athletes, authors begun to hypothesize if variability was a manifestation of a better functional level on the pursuit of a task goal. The relation between movement dynamics and task outcomes (Newell & Corcos, 1993) and the role of adaptive variability (term suggested by Handford et al., 1997) in relation of a Bootsma et al. (1991) article where the authors successfully relate movement variability with task performance, started to be addressed and laid the ground for the studies on movement synergies made nowadays.

Perceptual-information, under an ecological perspective, is essential, allowing feedback mechanisms and consequently on-line adaptations during movement execution. Under the assumption that on-line adaptations occur on the course of an action, time constraints and perceptual information availability will have a significant impact on that process. For instance, a ballistic movement and a slower tempo movement will have, inherently, a different number of opportunities to be corrected using feedback information (Zhao & Warren, 2015).

The role of perceptual information

The amount of perceptual information available on any given moment potentially guarantees how adaptive and robust the control mechanism based on feedback might be (Bastin & Montagne, 2005). The human nervous system perceptual-motor arrangement allows it to manage a large number of DOF and simultaneously prioritizes the most salient variables regarding task and environmental constraints (Bastin & Montagne, 2005). The authors stated that the ability to perform reasonably well under perceptual deprived scenarios was inherent to humans, this argument makes sense if its take in to account the notion of "global array" introduced by Stoffregen and Bardy (2001), which stated that the multitude of perceptual information that characterizes one specific, temporary situation, is perceived by humans as a single form of 'perceptual' energy called "global array".

Two research questions emerge from this concept: 1) how does a specific deprivation of a perceptual source might impair the robustness of the "global array"? 2) does skill level influence how much perceptual information an individual need to form his "global array"?

With the improvements on kinematic analysis of movement patterns, joint movement variability was much more present than expected, even for the same individual, on the same movement, under the same experimental conditions. These findings along with the notion that acknowledging a human system as computer was inherently flawed gave strength to constraint-led theories on motor control. Not only movement patterns showed variability but also the use of perceptual information was significantly different from individual to individual.

Müller and colleagues (2015) analyzed how highly skilled cricket batsmen used visual information in a batting task with temporal vision occlusion. The authors concluded that although the initiation of movement and weight transfer were significantly different between all the batsmen, the frequency of bat-ball contacts (i.e., goal of the task) was not. So, not only movement patterns might be different but also the use of perceptual information is subject of individual preference/convenience. This difference between coordination patterns achieving a similar outcome is known as motor equivalence, which is suggested by the authors to be an underlying control mechanism of complex whole body movement. (Müller et al., 2015).

Not only movement patterns formation depends of practice, so as perceptual attunement (Fajen et al., 2008). The ability to focus on the most relevant perceptual information is as crucial as the ability perform movement itself. Expertise will manifest itself different inter-individually, in a process where each human finds his/her own way of organizing the perception-action coupling. The enhancement of this ability only comes by practice, and that is why are expected better performances from experts than from novices.

Other important aspect regarding perceptual information management is the compensation of sensorial delays, which are biologically inherent. For adaptive behavior, depending on the situation, anticipation can play a significant role. The interaction with a moving external body might implicate the prediction of its future position, compensating a situational or neural delay is key to performance (Nijhawan & Wu, 2009). However, this might indicate that a model-based control (i.e., control based on a mental representation) could play a role in controlling actions when the perceptual or situational conditions are not propitious. Although on-line control is the main mechanism of control in the majority of movements in some cases (i.e., heavily perceptual deprived situations, ballistic movements etc.) anticipation plays a huge role in adaptive behavior. Rosalie and Müller (2013) found evidence that experts needed less time to pick-up useful information (i.e., in an occlusion situation) to anticipate actions than novices or even near-experts in Karate blocking situation.

Mazyn et al. (2007) (i.e., catching in the dark) and Scaleia et al. (2015) (i.e., target motion recognition) explain in two separate studies how humans use on-line control when the perceptual and time conditions are favorable, but if there is some kind of constraint which does not allowed this continuous control individuals shift to a model-based control. Both studies highlight the adaptability of the perceptual-motor system.

Maurer and Munzert (2013) stated that the familiarity with perceptual conditions has a high degree of relevance in skilled performance. Athletes are often encouraged to direct their attentional focus to the environment instead of using it to control their own actions. Although in the beginning stages of learning sport skills the attentional focus is directed at the self-aspects of the execution of a movement, gradually this attentional focus shifts to the environmental consequences of the execution of the movement, it goes from an internal focused perspective (i.e. which is always skill-focused) to an external focused perspective (i.e. which might be either skill-focused or environmental-focused) always directing attention to a movement-induced effect (Wulf, 2007; Wulf & Prinz, 2001). That's the normality for them, much so that, an alteration of attentional focus away from its normality will interfere with the proceduralized skill execution. This means, for expert performers, the automatization of skills is an important component of general performance. The concept of automatization requires consequently, a decreasing reliance on perceptual on-line control (Wulf, McNevin, & Shea, 2001). Whether is adapting the movement patterns, interpreting the perceptual information or enhancing the anticipation ability, it becomes glaring that movement performance relies a lot on experience. Expertise is a direct result of practice for a reason.

Compensatory variability

Variability has now a central role on motor control in what might be the ability to produce productive movement patterns as opposed to what happened in the past when it was considered noise or error. It's currently accepted that expert performers tend to demonstrate higher levels of movement variability than novices, while maintaining consistently better performances (Davids et al., 2003). Hence is a theoretically consequence concluding that movement variability might be a factor of success. But how so?

Kugler and Turvey (1987) state that in goal-directed movements the system is focused on the outcome of the action and not on the specific anatomical units involved, claiming that each act is functionally specific, and variability is no more than a tool of the system to preserve its function, which makes perfect sense as Davids and colleagues (2003) and Chow and colleagues (2008) hypothesize that variability has a positive role preventing the system from becoming too stable, stating that it might be a sign of exploratory behavior in order to keep function while in complex environments. Intentional and informational constraints have, under this perspective, an important role as learners search for new movement patterns.

Each individual movement performance is always dependent of the interaction between the learner characteristics and the availability of information, which are both unique to the individual – environment interaction (Chow et al., 2008).

With the advances on technological tools to make in-depth analysis of movement, authors started to focus on coordination profiling trying to analyze how each individual specifically organizes to satisfy task constraints. The hypothesis of variability being a systemic compensatory measure arose with Davids and colleagues (2003) when they realized for skilled shooters that higher levels of variability in the shoulder and elbow joints complemented each other to allow the wrist (the end effector) to stabilize its position (i.e., and therefore hit target better). This compensatory variability was not present in unskilled shooters. In fact, less skilled shooters showed more stability in the shoulder and elbow joints which resulted in a more rigid (i.e., incapable of adapting to the situation) pattern that ultimately decreased performance values due to an increase and undesirable variability of the end effector.

Having that in regard other research questions emerge: 1) in basketball dribbling, should we expect higher levels of variability in the proximal joints (i.e. shoulder and elbow) and lower variability in the end-effector joint (i.e. wrist)? 2) Do the first ones co-vary between them in order to stabilize the latter one?

Uncontrolled manifold

The relation between the variability of two or more variables in order to stabilize a performance goal, is called a synergy (Schöner and Scholz, 1999; Latash, 2010). In a biological movement system, the muscles and joints are responsible for assembling highly reliable, stable and reproducible coordination patterns (Bernstein, 1967).

The organs that confer muscles and tendons sensitivity, usually referred as just managers of reflex muscular activity, are key for what Turvey (1998) calls effortful or dynamic touch, as they are able to keep rotational dynamics invariant over variations in the rotational forces and motions. Cordo and colleagues (1994) also brought knowledge within this line of thought explaining that a proprioceptive input of a given joint would trigger the movement of a subsequent joint laying the biological grounds (along with Turvey) for the explanation of compensatory variability. Spinal and transcortical reflex loops participate in what is the automatic correction of changes in muscle length allowing the compensation of muscle stiffness at a subconscious level (Park et al., 1999). This compensation might not happen just at an intra-muscular level but also at an inter-muscular level as Turvey (1998) had previously discovered. This contribution of the proprioceptive system to automatically regulate part of the movement provides the system with efficiency and flexibility in goal-directed movements. The contributions of the proprioceptive system are intrinsic to the control of voluntary movement, and the motor system continuously interacts with the sensory system in order to meet specific task demands (Park et al., 1999).

This is central for the compensatory variability theory (Davids et al., 2003). The fact that our muscular system might compensate itself subconsciously, lightens the processing burden of a hypothesis that defend that the central nervous system had to control all the components of the system at all times.

Conceptually, transferring the informational load to a subconscious, uncontrolled space (i.e. where variables are freed from the need of being consciously controlled), simplifies processes and just makes sense when analyzing time constrained movements. Regarding perceptual information either visual or auditory both must rely on this muscular-articular linkage ability to perform adaptive movements when many muscles are involved. Along with visual and auditory perception, haptic perceptual information and its inherence to movement, create a plethora of degrees of freedom where coherence, coordination and consistency against perturbations is always ensured (Turvey, 1998).

To finally have a broad understanding about motor control and coordination, we need to fully understand how do synergies are formed, when do they formed and how synergies formation can be associated with a successful performance. The concept of synergy consisted, as we already said, on two or more variables co-varying between them in order stabilize a performance goal. But what motivated the first approach by Scholz and colleagues (2000) was the Bernstein (1967) question: how does the human movement system controls an unfathomable number of degrees of freedom? Since the computing theory was conceptually flawed, how could a system organize itself so the burden of processing would not be overwhelming. The authors found that there were numerous joint combinations that did not led to changes in performance goal values, so they predicted that joint variables variability which did not influenced directly performance goal values would be less controlled than variables which influenced directly the performance goal (Scholz & Schöner, 1999).

With this assumption, they suggest that task-relevant elements (e.g. shoulder and elbow angles) in which variability values did not affect performance values are released from conscious control contrary to what happens with the other task-relevant elements (e.g. wrist height) in which variability directly affected performance values are consciously controlled.

Along the study, the authors found that task-relevant elements consciously controlled structured the joint control system throughout the whole movement, releasing the DOF on the remaining elements as a condition for successful performance. It is important to stress that not all variables can be released from control, just the ones that do not contribute directly to performance. Generally, for the consciously controlled one's stability is the goal.

Just because some variables are released from conscious control does mean that they are irrelevant obviously, they are assessed this way because if we look to their behavior alone they do not have any kind of direct effect on performance, there is no correlation. Nonetheless, if we examine its behavior along other similar task-relevant variables we can conclude that they might co-vary between them in order to stabilize a consciously controlled variable. When this happens (i.e. two variables co-varying in order to stabilize other one) it means that a synergy is happening.

This explains why motor equivalence exists. Uncontrolled task-relevant variables behavior might produce ever-different movement patterns but still achieve consistently similar outcomes (Cruse and Brüwer, 1987; Cruse et al., 1993). Biological explanations given by the authors (Scholz et al., 2000) are conceptually similar of previous studies mentioned here (e.g., Turvey et al., 1998; Park et al., 1999; Cordo et al., 1994) attributing the responsibility of joint-to-joint behavior to viscoelastic properties of the motor apparatus, managing muscle stiffness along the movement.

This theory is called *uncontrolled manifold theory* (UCM) where the uncontrolled manifold is the subspace where task-relevant variables values do not interfere with performance values (Scholz, Schöner & Latash, 2000). Although this non-interference might be interpreted as irrelevant for performance it is not, this subspace provides the system flexibility to adapt its movement patterns to perturbation while maintaining the stability in consciously controlled task-relevant variables. The ability to produce the same outcomes with different movement patterns is called motor redundancy, that should be viewed as a problem but an inherent part of the solution in movement coordination (Gelfand & Latash, 1998).

Dissimilarity analysis

Quantifying moving trajectories dissimilarity in order to precisely measure differences on variables in which stability is a performance factor might be the answer to identify how much a specific condition affected performance. Although literature does not offer a vast number of methods to solve this problem, quantifying moving trajectories dissimilarity is key to sports performance, motor rehabilitation or even medical surgical contexts (Passos et al., 2017).

If stability values of a joint position influenced positively performance, consequently its disturbance would affect negatively performance. Generally, variables that affect directly performance values (i.e. in which their variance causes performance values variance) are located in the end of the kinetic chain and are known as end-effector variables (Scholz & Schöner, 1999). If we could measure the level of disturbance that an occlusion condition caused to performance we could identify the contribution of a specific perceptual source for task motor control. Through advanced geometrical methodologies we intend to, using the occlusion paradigm (Heinen & Vinken, 2001), understand how much is the end-effector joint position (Scholz & Schöner, 1999) affected by different conditions within and both two groups with distinct levels of experience.

Research questions

Regarding the task selected as the methodological basis of this thesis, a basketball dribbling task, the main goal was to contribute on the theoretical understanding on how is the basketball dribble controlled being a cyclical perceptually challenging task involving an external element (i.e. the ball) with which the individual loses temporary (haptic, auditory and visual) contact every cycle. To do so, we will analyze a multitude of joint variables (e.g. positions, angles) in two separate groups, one amateur group and a professional group.

In order to identify the role of variability, stability and synergies within and between joints, we will try to understand how amateurs and professionals deal with perceptually deprived scenarios (i.e. auditory and/or peripheral vision), and how does skill level influences the adaptations that take place. The study is based on the reasonable assumption that professionals are better at controlling the dribble compared to amateurs, indicating that the significant differences between both groups in certain variables can somehow represent the development of dribble control. Ultimately, the study can provide directions on what really is expected from a better dribbler and therefore, what aspects can a coach focus on in order to develop the dribble motor control.

The thesis is divided by three articles, each one’s structure depends on respective journals required format specificities, hence the chapters and subchapters between studies might differ. The data collection for these three studies took place between September, 2018 and November, 2018 at Faculdade de Motricidade Humana, Universidade de Lisboa.

In the first article, we will try to understand how does a perceptual deprived situation (i.e. peripheral vision occlusion, auditory occlusion or both occlusions) influences joint variability (i.e. shoulder, elbow and wrist) in professionals and amateurs, between and within groups. In the second article, we will try to determine the existence of synergies in the dribbling cycle, in both groups, and if those synergies are constant during the whole movement cycle. The third and final article will analyze both groups dribbling wrist trajectories, also under perceptual deprived conditions, trying to assess how mathematically different are these trajectories and how does the level of experience and perceptual occlusion might influence the magnitude of the difference.

The goal of the thesis is thoroughly identifying what characterizes a skilled dribbler from a novice one, establishing the foundations to have a better understanding on how motor control operates on basketball dribble.

Article 1

The role of variability in the control of the basketball dribble under different perceptual setups

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Abstract

When executing a sport specific movement, athletes cannot use all perceptual resources to control their actions. The complexity of a basketball match, demands that individuals command their attention towards the context to make decisions. The dependency on the perceptual sources to control a movement should be kept to a minimum. During a match due to situational constraints, players often see themselves with impaired perceptual sources (e.g., auditory and peripheral vision occlusions). Assuming that professional basketball players are more skilled than amateurs, we analysed how both groups were affected by perceptual impairment, within and in-between groups in a dribbling task. A variability analysis (correlation dimension, approximate entropy and Lyapunov exponent) was used to evaluate how an increased variability or stability, in a specific joint movement, contributes to a better adaptive behaviour when facing perceptual impairment. Professionals showed a significantly lower variability of the wrist movements, but had a significantly higher value of variability in the shoulder horizontal movements (anterior-posterior and lateral), and also in the lateral elbow movements when their downwards peripheral vision was impaired. The increase in variability in such joint movements reflects adaptive behaviour and might be a performance factor.

Keywords

Perceptual Occlusion; Motor Skills; Visual Perception; Adaptive Behavior; Motor Performance

Introduction

Actions were previously conceptualised as specialized relationships between biological organisms and specific environments (Davids, Glazier, Araújo & Bartlett, 2003). This specificity of environment-performer interaction highlights the relevance and availability of perceptual information in the control of actions (Gibson, 1977; Handford, Davids, Bennett & Button, 1997). This means that when the individual has enough time to pick up perceptual information he/she will prioritize using that information to help control his/her actions instead of using a model-based control strategy (Zhao & Warren, 2015). During each movement, new information fluxes are constantly created or updated based on ongoing perceptual information, which contributes to the adaptive coordination patterns of the neuromuscular system. The capacity to handle several sources (i.e., visual, auditory, proprioceptive, haptic) of perceptual information is as important as the ability to act. This means that actions change the energy fluxes contributing for the perceptual information, which sustain forthcoming actions (Gibson, 1977; Fajen, Riley & Turvey, 2009). Stoffregen and Bardy (2001) concluded that although the source of perceptual information may vary in the course of an action, information itself is integrated by the individual not as independent sources but all together forming an energy flux that the authors nominated as a "global array". A temporary disruption of any perceptual source that contributes to the global array may impair the individual-environment interaction diminishing the quality of performance.

Sports actions, as dribbling in a basketball competitive situation, are influenced by spatial constraints (e.g., distance to goal), by temporal constraints (e.g., shot clock), and also by individual constraints such as the previous knowledge regarding the action to perform and the player ability to do online corrections supported by ongoing information during the course of the dribbling action (Chow, Davids, Button & Rein, 2008). To assess the relevance of a perceptual source of information for the performance of a task, motor control research usually creates experimental designs in which the participants are invited to perform a specific action but occluded from the perceptual sources under analysis (e.g., Heinen & Vinken, 2001).

Previous research with the visual occlusion paradigm in gymnastics revealed the importance of visual information for the performance of the handspring on vault (Heinen & Vinken, 2001). However, the physical characteristics of the tool with which the gymnast must interact remain stable contrary to what happens in other sports which involve a ball as task constraint, such as basketball. In this study, we propose to analyse the influence of perceptual information (e.g., visual; auditory) on an interceptive task, in which the position of the tool (i.e., a ball) with which the participant must interact changes due to his/her own action.

Human's ability to display adaptive behaviour to an ever-changing environment depends on the "perceptual attunement to different informational variables as conditions change" (Fajen et al., 2008, pp.85). Attunement is a form of perceptual learning, characterized by a perceptual convergence onto more effective optical, auditory or proprioceptive variables (Fajen, 2005). This ability is often a criterion for performance success especially in perceptual depriving environments (Bennett, Button, Kingsbury, & Davids, 1999; Stoffregen & Bardy, 2001).

The occlusion of one perceptual source that contributes to the individual-environment linkage may drive the participant to search for relevant information with the available perceptual sources. Concerning sport actions this perceptual 'replacement' raises a few issues, for instance it remains unknown if the occlusion of visual information during the basketball dribbling action can be compensated by other perceptual sources without disturbing the dribbling action.

So far, research demonstrates that the occlusion of a single perceptual source impairs motor performance (Heinen & Vinken, 2001). But, the cumulative effects of occlusion of more than one perceptual source remains an issue to be studied. The visual and auditory perceptual sources are often impaired in competitive social settings as a basketball match. Often the ball carrier has to direct his/her visual attentional focus towards the environment (e.g., to teammates and/or opponent's relative positions), using it less to control the ball itself (if needed). Auditory information is often occluded, especially when one is playing in a sell-out arena, where the noise of a supportive or non-supportive audience may disturb player's auditory information. Competitive situations with 'gaps' on perceptual information (e.g., visual, auditory) are recurrent during the course of a match. However, even under these conditions, players are able to keep the dribbling action under control, which make us wonder about the relevance of these perceptual information for the control of the dribbling.

The notion of redundancy, inherent to the multiple degrees of freedom of the body (due to joint, muscle and nervous system characteristics) means that the human movement system is able to accomplish any given task with more than one strategy, producing multiple behavioural patterns required for adaptive behaviours performance (Bernstein, 1967). A common misunderstanding is to interpret movement variability as a result of random processes (i.e., noise) (Pool, 1989). The so-called "noise" often reveals important information about the human movement system (Buzzi, Stergiou, Kurz, Hageman & Heidel, 2003). There is an increasing evidence on how important variability is in human movement, often labeling it as a necessary condition for maintain or improving performance. Variability manifests itself through the multiple options of movement, creating flexible and adaptive forms for task completion, reflecting how adaptable a skill can be under the influence of internal and external disturbance (Harbourne & Stergiou, 2009). This adaptive feature could be a main reason why movement variability is greater in skillful individuals when compared to novices (Siegler, 1996). Joint variability during the performance of a task allows the movement system to be relatively stable when it needs to be, and to be flexible when it needs to adapt to intrinsic or extrinsic changes maintaining the ongoing action.

A nonlinear analysis allows the understanding of the dynamics of variability within the system (Buzzi et al., 2003). Linear analysis tools often mask variability, since the values are averaged to generate a mean ensemble curve that is used to define the average "picture" of the data. Moreover, this averaging procedure is usually coupled with time normalization, which means that data is "stretched" from its original form (Buzzi et al., 2003). To avoid the loss of temporal variations due to time normalization, the literature suggests the use of nonlinear techniques, in which the focus of the analysis is on how data pattern changes over time (Dingwell & Cusumano, 2000; Hausdorff, Mitchell, Firtion, Peng, Cudkowicz, Wei & Goldberger, 1997).

The most common nonlinear tools to assess variability in human movement systems are: correlation dimension (COD); approximate entropy (ApEn) and Lyapunov exponent (LyE).

Correlation dimension (COD) is a measure that analyzes the positional makeup of data points within a state space. This nonlinear variable is usually considered accurate with small data sets because it assesses areas of space that actually contain data points (Sprott & Rowlands, 1992; Grassberger & Procaccia, 1983a, b). COD will have higher values when the data set has a completely random distribution, while it will assume smaller values in deterministic data sets (Buzzi et al., 2003).

Approximate entropy (ApEn) is a measure of complexity (Pincus, 1991), representing the lack of regularity of a given behavioral system, which is useful to describe how predictable a movement might be. In repetitive (regular) patterns, the ApEn will assume low values, whereas for random data sets, it will have higher values, and for deterministic data sets assumes intermediate values (Pincus & Goldberger, 1994).

The Lyapunov exponent (LyE) is a measure of repeatability of a dynamical system that quantifies the divergence between movement trajectories (Buzzi et al., 2003). In movement trajectories, as nearby points separate they produce instability (Dingwell & Cusumano, 2000; Wolf, Swift, Swinney & Vastano, 1985). If the movement of a system is highly stable, the data trajectories between repetitions do not display any divergence, which means they overlap which is consistent with low values of LyE. On the contrary, noisy (highly irregular) data sets display divergence on movement trajectories, which is consistent with high values of LyE (Rapp, 1994; Theiler, Eubank, Longtin, Galdrikian & Farmer, 1992; Sprott & Rowlands, 1992; Grassberger & Procaccia, 1983b).

In the current study, we aimed to describe the dominant arm movement variability during the dribbling action in basketball under impaired sensorial conditions. Moreover, the participant's skill level may contribute to differences in the dominant arm movement variability. Therefore, we hypothesized that both perceptual impairment and participant's skill level influence the dominant arm movement variability during the dribbling action in basketball.

Materials and Methods

The study had twenty participants assigned to two groups according to skill level: an amateur group and a professional group. The amateur group included ten grad-students (6 men, 4 women) in sport sciences with no competitive experience of basketball. Resembling to contemporary studies (e.g., Sholz & Schöner, 1999; Klous, Danna-dos-Santos & Latash, 2010; Romero, Kallen, Riley & Richardson, 2015), we opted to use both genders individuals. The age of the participants ranged between 18 and 26 years old (mean = 19.4, SD = 2.9). To be included in the professional group, the participants needed to have at least 3 years of playing experience and to play on a team placed on the top 2 national leagues. The professional group included 10 athletes (8 men, 2 women). The age of the participants ranged between 18 and 31 years old (mean= 23.3, SD = 3.8).

The sample size was estimated using F-tests (ANOVA Repeated Measures Within Factors) for a group and 4 measurements, with a medium effect size of 0.25, an alpha error probability of 0.05, a beta error probability of 0.20, and a correlation among measures of 0.80, which provided a total sample size per group of 10 subjects. This procedure was performed using the GPower software (Universität Düsseldorf, Germany).

The participants were asked to execute successfully four trials of 42 consecutive dribbles in basketball with the dominant arm in a stationary position (i.e., without locomotion). Each participant performed one trial under each of the following experimental conditions: i) dribbling with no occlusion (NO); ii) dribbling with visual occlusion (VO); iii) dribbling with auditory occlusion (AO); iv) dribbling with both visual and auditory occlusion (BO). The sequence of these four experimental conditions was randomly selected for each individual.

In the first condition (i.e., dribbling with no occlusion), the participants were asked to perform a dribbling action in basketball without occluding any perceptual source; in the second condition, the participants were asked to perform the basketball dribbling action with occlusion goggles which inhibits downwards peripheral vision, preventing the participant to capture visual information from the ball while performing the dribbling action; in the third condition, the subjects were asked to perform the basketball dribbling action using headphones that totally prevent the participant to receive auditory information related to the bouncing ball while performing the trial; in the fourth condition, the subjects were asked to perform the basketball dribbling action with both perceptual sources simultaneous occluded, the peripheral vision (using the occlusion goggles) and the audition (using the headphones), which prevents the participants to capture visual and auditory information while performing the basketball dribbling action. Prior to task performance, the participants were informed with standardized task instructions about the experimental procedures regarding the visual and auditory occlusion.

The experimental setup was assembled in an indoor laboratory room. The basketball ball (size 7) is in accordance with the official FIBA measures. The following tools were also used: four spherical reflective markers to be placed in the third metacarpal epiphysis of the dominant hand, on the wrist, elbow and shoulder of the same side; double-sided adhesive tape (to fixate the reflective marker); a pair of goggles to occlude downwards peripheral vision; a set of headphones Beats by Dre© to isolate external noise and a mp3 player to play a continuous white noise sound to block out any external sound information.

The three-dimensional (3D) participant's movements while dribbling was captured with a sample frequency of 120 Hz (Motive 2.1.1 by Optitrack©). For that purpose, six Prime 13 by Optitrack© cameras were used. Motive software recorded the 3D coordinates (i.e., sagittal axis, frontal axis and longitudinal axis) of the marked points. The time series were then exported as csv file. Finally, MATLAB (version R2019a) routines were used to analyse the 3D coordinates of the marked points and to calculate the dependent variables required to analyse the dribbling action.

The four experimental conditions (i.e., NO, VO, AO, BO) were used as independent variables. The variability of the hand, wrist, elbow and shoulder, were used as dependent variables.

To analyse the variability of each dependent variable, the following nonlinear tools were used: i) Correlation dimension (COD), to assess data distribution within a state space; ii) Approximate entropy (ApEn), to analyse the predictability of the system; iii) Lyapunov exponent (LyE), to evaluate how much the system diverged from the initial data trajectories.

The first stage consisted on performing a descriptive analysis of mean values and standard deviations of COD, ApEn and LyE for each dependent variable in each experimental condition. Then, the normality and the sphericity conditions were assessed using Shapiro-Wilk's tests and Mauchly's tests, respectively. The statistical comparison of the mean values of each variable across the four conditions was performed through analysis of variance (ANOVA) with repeated measures and Bonferroni's post-hoc for each group. Finally, T-Tests for independent samples were performed to compare the values between the amateur and professional groups for each of the four experimental conditions. The probability of .05 was set as the criterion for statistical significance. This part of the study was undertaken using the IBM SPSS software (version 25, IBM Inc., USA).

All the participants were voluntary and signed an informed consent form. The Ethics Committee of the Faculdade de Motricidade Humana, Universidade de Lisboa approved the study that was conducted according to the principles expressed in the Declaration of Helsinki.

Results

A plethora of results emerged from our analysis; we will try to present those which we understand to be crucial to identify how different impaired perceptual conditions influences amateurs and professionals, within and in-between groups.

All the participants from both groups were able to maintain the 42 consecutive dribbles for all experimental conditions, which was the condition to a successful performance.

The joint movements were classified on three axes: sagittal (i.e., anterior-posterior; back-forth); frontal (i.e., lateral; left-right); and longitudinal (i.e., up-down). For COD, ApEn and LyE, the lowest value corresponds to the highest stability a variable can achieved.

(next page)

Within Groups Comparison

Amateurs

Table 1a. Amateurs' variability values under the four experimental conditions

	Amateur group					
	NO	VO	AO	BO	*p-value*	*Post-hoc p-value*
Anterior-Posterior (sagittal axis)						
Wrist						
COD	3.93 ± 0.29	3.94 ± 0.37	4.06 ± 0.23	3.99 ± 0.44	.803	
ApEn	0.13 ± 0.05	0.20 ± 0.04	0.13 ± 0.03	0.21 ± 0.10	.015 *	VO vs. AO .023 *
LyE	2.96 ± 0.83	2.97 ± 0.77	3.32 ± 0.56	2.80 ± 0.72	.327	
Elbow						
COD	3.53 ± 0.27	3.48 ± 0.19	3.62 ± 0.16	3.52 ± 0.25	.968	
ApEn	0.21 ± 0.05	0.26 ± 0.06	0.20 ± 0.06	0.26 ± 0.09	.024 *	BO vs. AO .028 *; AO vs. VO .017 *
LyE	3.28 ± 0.58	3.61 ± 0.70	3.39 ± 0.46	3.35 ± 0.68	.455	
Shoulder						
COD	4.09 ± 0.53	3.92 ± 0.48	4.20 ± 0.27	4.02 ± 0.45	.170	
ApEn	0.19 ± 0.06	0.20 ± 0.05	0.14 ± 0.04	0.21 ± 0.07	.035 *	NO vs. AO .009 *
LyE	2.24 ± 0.88	1.57 ± 1.16	2.75 ± 0.67	1.85 ± 1.04	.012 *	AO vs. VO .008 *
Lateral (frontal axis)						
Wrist						
COD	4.17 ± 0.34	3.99 ± 0.27	4.02 ± 0.28	3.84 ± 0.49	.250	
ApEn	0.15 ± 0.04	0.20 ± 0.06	0.16 ± 0.05	0.21 ± 0.08	.027 *	BO vs. NO .027 *
LyE	3.20 ± 1.00	2.61 ± 1.08	3.42 ± 0.53	3.07 ± 0.64	.135	
Elbow						
COD	4.22 ± 0.21	4.10 ± 0.26	4.15 ± 0.24	4.09 ± 0.36	.724	
ApEn	0.12 ± 0.03	0.18 ± 0.05	0.14 ± 0.03	0.18 ± 0.07	.017 *	NO vs. VO .045 *
LyE	3.10 ± 0.71	3.24 ± 0.85	3.03 ± 1.05	3.23 ± 0.46	.830	
Shoulder						
COD	3.77 ± 0.61	3.54 ± 0.26	3.91 ± 0.56	3.70 ± 0.48	.173	
ApEn	0.21 ± 0.05	0.24 ± 0.05	0.18 ± 0.05	0.25 ± 0.07	.019 *	BO vs. AO .038 *; AO vs. VO .044 *
LyE	1.75 ± 1.28	1.36 ± 0.95	2.34 ± 1.15	1.37 ± 1.17	.187	
Longitudinal (longitudinal axis)						
Wrist						
COD	3.44 ± 0.21	3.28 ± 0.23	3.33 ± 0.10	3.33 ± 0.13	.219	
ApEn	0.40 ± 0.06	0.37 ± 0.07	0.41 ± 0.06	0.40 ± 0.05	.190	
LyE	2.90 ± 0.68	2.79 ± 0.73	3.11 ± 0.57	2.80 ± 0.62	.586	
Elbow						
COD	3.82 ± 0.46	3.70 ± 0.41	3.88 ± 0.30	3.72 ± 0.43	.239	
ApEn	0.22 ± 0.07	0.26 ± 0.06	0.23 ± 0.07	0.30 ± 0.11	.016 *	BO vs. AO .030 *; BO vs. NO .018 *
LyE	3.51 ± 0.75	2.81 ± 1.18	3.85 ± 0.98	2.69 ± 1.00	.021 *	BO vs. NO .022 *; VO vs. AO .016 *
Shoulder						
COD	3.95 ± 0.33	3.65 ± 0.21	3.83 ± 0.29	3.61 ± 0.36	.001 *	NO vs, VO .017 *
ApEn	0.22 ± 0.07	0.26 ± 0.06	0.21 ± 0.06	0.26 ± 0.05	.040 *	BO vs. AO .011 *
LyE	3.39 ± 1.61	2.12 ± 1.14	3.81 ± 1.10	2.19 ± 1.38	.011 *	AO vs. VO .005 *

Note. Studied parameters for the first group (amateur) in the four conditions (NO – no occlusion; VO – downwards peripheral visual occlusion; AO – auditory occlusion; BO – both occlusions). COD – correlation dimension; ApEn – approximate entropy; LyE – Lyapunov exponent. The values are means ± standard deviations and the significant differences are highlighted with an asterisk (p< .05).

Professionals

Table 1b. Professionals' variability values under the four experimental conditions

	Professional group					
	NO	VO	AO	BO	*p-value*	*Post-hoc p-value*
Anterior-Posterior (sagittal axis)						
Wrist						
COD	3.90 ± 0.24	3.77 ± 0.28	3.96 ± 0.33	3.83 ± 0.28	.225	
ApEn	0.16 ± 0.04	0.20 ± 0.04	0.13 ± 0.03	0.15 ± 0.06	.133	
LyE	2.78 ± 0.38	2.83 ± 0.46	2.88 ± 0.57	2.74 ± 0.49	.869	
Elbow						
COD	3.58 ± 0.23	3.45 ± 0.21	3.61 ± 0.35	3.56 ± 0.09	.464	
ApEn	0.26 ± 0.08	0.27 ± 0.08	0.25 ± 0.09	0.29 ± 0.08	.111	
LyE	2.89 ± 0.32	2.84 ± 0.38	2.82 ± 0.51	2.72 ± 0.59	.774	
Shoulder						
COD	4.15 ± 0.31	3.90 ± 0.14	4.04 ± 0.40	4.08 ± 0.34	.170	
ApEn	0.16 ± 0.06	0.17 ± 0.07	0.19 ± 0.09	0.17 ± 0.08	.466	
LyE	2.34 ± 1.23	2.52 ± 0.43	2.48 ± 0.60	2.47 ± 0.65	.960	
Lateral (frontal axis)						
Wrist						
COD	4.11 ± 0.34	4.22 ± 0.29	4.07 ± 0.32	4.08 ± 0.02	.334	
ApEn	0.15 ± 0.04	0.13 ± 0.04	0.15 ± 0.05	0.14 ± 0.04	.548	
LyE	3.00 ± 0.71	2.90 ± 0.47	2.83 ± 0.65	3.18 ± 0.54	.467	
Elbow						
COD	4.45 ± 0.25	4.43 ± 0.16	4.22 ± 0.26	4.42 ± 0.18	.083	
ApEn	0.11 ± 0.02	0.11 ± 0.03	0.12 ± 0.03	0.12 ± 0.03	.393	
LyE	3.92 ± 1.12	3.83 ± 1.13	3.75 ± 1.18	3.87 ± 1.13	.963	
Shoulder						
COD	3.79 ± 0.35	3.95 ± 0.31	3.87 ± 0.41	3.79 ± 0.33	.470	
ApEn	0.14 ± 0.04	0.14 ± 0.02	0.13 ± 0.05	0.16 ± 0.05	.376	
LyE	2.19 ± 0.60	2.77 ± 1.00	2.45 ± 1.04	2.71 ± 0.70	.052	
Longitudinal (longitudinal axis)						
Wrist						
COD	3.23 ± 0.12	3.25 ± 0.22	3.33 ± 0.27	3.31 ± 0.13	.592	
ApEn	0.33 ± 0.05	0.36 ± 0.05	0.37 ± 0.07	0.36 ± 0.07	.108	
LyE	2.17 ± 0.46	2.47 ± 0.38	2.40 ± 0.35	2.20 ± 0.52	.264	
Elbow						
COD	3.73 ± 0.29	3.78 ± 0.37	3.60 ± 0.31	3.69 ± 0.31	.256	
ApEn	0.22 ± 0.08	0.24 ± 0.08	0.23 ± 0.05	0.25 ± 0.08	.746	
LyE	2.87 ± 0.65	2.96 ± 0.39	2.59 ± 0.46	2.48 ± 0.45	.029 *	BO vs. VO .029 *
Shoulder						
COD	3.75 ± 0.29	3.67 ± 0.25	3.51 ± 0.21	3.85 ± 0.35	.014 *	BO vs. AO .012 *; AO vs. NO .011 *
ApEn	0.20 ± 0.07	0.22 ± 0.09	0.21 ± 0.06	0.19 ± 0.06	.582	
LyE	2.68 ± 0.73	2.55 ± 0.52	2.53 ± 0.50	2.28 ± 0.31	.296	

Note. Studied parameters for the second group (professional) in the four conditions (NO – no occlusion; VO – downwards peripheral visual occlusion; AO – auditory occlusion; BO – both occlusions). COD – correlation dimension; ApEn – approximate entropy; LyE – Lyapunov exponent. The values are means ± standard deviations and the significant differences are highlighted with an asterisk (p< .05).

At first glance, the most noticeable fact when observing the results is that amateurs had more significant differences in joint movement variability between conditions than professionals. Furthermore, in both groups, elbow and shoulder joints seemed to have their movement variability more affected by occlusions than the wrist.

In-Between Groups Comparison

When comparing amateurs to professionals in a no occlusion setup, there were some variables with significant differences ($p < .05$) and others with tendencies towards significance ($.05 < p < .08$). More precisely, amateurs showed a statistical tendency to have higher variability in anterior-posterior (p= .076) and up-down (p= .055) elbow movements (i.e., LyE analysis). Concerning lateral elbow movements, professionals showed a significantly higher variability in the COD analysis (p= .045); the LyE analysis confirmed the result with a statistical tendency (p= .069). In the lateral shoulder movements, the amateurs showed a significantly higher variability (p= .002) (i.e., ApEn analysis). Regarding the wrist up-down movements, all three variables (i.e., COD, ApEn and LyE) confirmed a significantly higher variability in the amateurs (p= .010; p= .009; p= .012, respectively).

The table 2 shows the results for the remaining conditions.

(next page)

Table 2. Comparison of amateurs vs. professionals' variability under perceptual occlusion

	Peripheral vision occlusion			**Auditory occlusion**			**Both occlusions**		
	AM	PRO	*p-value*	AM	PRO	*p-value*	AM	PRO	*p-value*
Anterior-Posterior (sagittal axis)									
Wrist									
COD	3.94 ± 0.37	3.77 ± 0.28	.260	4.06 ± 0.23	3.96 ± 0.33	.420	3.99 ± 0.44	3.83 ± 0.28	.358
ApEn	0.20 ± 0.04	0.13 ± 0.05	.003 *	0.13 ± 0.03	0.12 ± 0.05	.657	0.21 ± 0.10	0.15 ± 0.06	.106
LyE	2.97 ± 0.77	2.83 ± 0.46	.648	3.32 ± 0.56	2.88 ± 0.57	.098	2.80 ± 0.72	2.74 ± 0.49	.845
Elbow									
COD	3.48 ± 0.19	3.45 ± 0.21	.755	3.62 ± 0.16	3.61 ± 0.35	.946	3.52 ± 0.25	3.56 ± 0.09	.685
ApEn	0.26 ± 0.06	0.27 ± 0.08	.713	0.20 ± 0.06	0.25 ± 0.09	.116	0.26 ± 0.09	0.29 ± 0.08	.375
LyE	3.61 ± 0.70	2.84 ± 0.38	.007 *	3.39 ± 0.46	2.82 ± 0.51	.016 *	3.35 ± 0.68	2.72 ± 0.59	.041 *
Shoulder									
COD	3.92 ± 0.48	3.90 ± 0.14	.895	4.20 ± 0.27	4.04 ± 0.40	.325	4.02 ± 0.45	4.08 ± 0.34	.765
ApEn	0.20 ± 0.05	0.17 ± 0.07	.299	0.14 ± 0.04	0.19 ± 0.09	.116	0.21 ± 0.07	0.17 ± 0.08	.346
LyE	1.57 ± 1.16	2.52 ± 0.43	.026 *	2.75 ± 0.67	2.48 ± 0.60	.346	1.85 ± 1.04	2.47 ± 0.65	.129
Lateral (frontal axis)									
Wrist									
COD	3.99 ± 0.27	4.22 ± 0.29	.088	4.02 ± 0.28	4.07 ± 0.32	.689	3.84 ± 0.49	4.08 ± 0.02	.167
ApEn	0.20 ± 0.06	0.13 ± 0.04	.004 *	0.16 ± 0.05	0.15 ± 0.05	.664	0.21 ± 0.08	0.14 ± 0.04	.024 *
LyE	2.61 ± 1.08	2.90 ± 0.47	.451	3.42 ± 0.53	2.83 ± 0.65	.038 *	3.07 ± 0.64	3.18 ± 0.54	.704
Elbow									
COD	4.10 ± 0.26	4.43 ± 0.16	.003 *	4.15 ± 0.24	4.22 ± 0.26	.513	4.09 ± 0.36	4.42 ± 0.18	.022 *
ApEn	0.18 ± 0.05	0.11 ± 0.03	.000 *	0.14 ± 0.03	0.12 ± 0.03	.167	0.18 ± 0.07	0.12 ± 0.03	.054
LyE	3.24 ± 0.85	3.83 ± 1.13	.203	3.03 ± 1.05	3.75 ± 1.18	.166	3.23 ± 0.46	3.87 ± 1.13	.114
Shoulder									
COD	3.54 ± 0.26	3.95 ± 0.31	.005 *	3.91 ± 0.56	3.87 ± 0.41	.882	3.70 ± 0.48	3.79 ± 0.33	.632
ApEn	0.24 ± 0.05	0.14 ± 0.02	.000 *	0.18 ± 0.05	0.13 ± 0.05	.047 *	0.25 ± 0.07	0.16 ± 0.05	.003 *
LyE	1.36 ± 0.95	2.77 ± 1.00	.005 *	2.34 ± 1.15	2.45 ± 1.04	.834	1.37 ± 1.17	2.71 ± 0.70	.006 *
Longitudinal (longitudinal axis)									
Wrist									
COD	3.28 ± 0.23	3.25 ± 0.22	.790	3.33 ± 0.10	3.33 ± 0.27	.993	3.33 ± 0.13	3.31 ± 0.13	.775
ApEn	0.37 ± 0.07	0.36 ± 0.05	.812	0.41 ± 0.06	0.37 ± 0.07	.193	0.40 ± 0.05	0.36 ± 0.07	.263
LyE	2.79 ± 0.73	2.47 ± 0.38	.233	3.11 ± 0.57	2.40 ± 0.35	.004 *	2.80 ± 0.62	2.20 ± 0.52	.030 *
Elbow									
COD	3.70 ± 0.41	3.78 ± 0.37	.657	3.88 ± 0.30	3.60 ± 0.31	.058	3.72 ± 0.43	3.69 ± 0.31	.848
ApEn	0.26 ± 0.06	0.24 ± 0.08	.570	0.23 ± 0.07	0.23 ± 0.05	.927	0.30 ± 0.11	0.25 ± 0.08	.341
LyE	2.81 ± 1.18	2.96 ± 0.39	.719	3.85 ± 0.98	2.59 ± 0.46	.002 *	2.69 ± 1.00	2.48 ± 0.45	.549
Shoulder									
COD	3.65 ± 0.21	3.67 ± 0.25	.845	3.83 ± 0.29	3.51 ± 0.21	.011 *	3.61 ± 0.36	3.85 ± 0.35	.159
ApEn	0.26 ± 0.06	0.22 ± 0.09	.172	0.21 ± 0.06	0.21 ± 0.06	.954	0.26 ± 0.05	0.19 ± 0.06	.013 *
LyE	2.12 ± 1.14	2.55 ± 0.52	.290	3.81 ± 1.10	2.53 ± 0.50	.003 *	2.19 ± 1.38	2.28 ± 0.31	.839

Note. Studied parameters for each condition (visual, auditory, both) in the two groups (AM – amateur group; PRO – professional group). COD – correlation dimension; ApEn – approximate entropy; LyE – Lyapunov exponent. The values are means ± standard deviations and the significant differences are highlighted with an asterisk (p< .05).

Reviewing the differences between groups in each condition, and taking into account statistical significance and values of variability, some overall results can be highlighted as noteworthy: amateurs show, consistently and throughout all the conditions and planes of movement, a higher variability in wrist movement. Elbow lateral movement variability displayed higher values in the professionals' group under downwards peripheral vision occlusion and both occlusion conditions. The professionals also displayed a higher variability of shoulder movement in the horizontal plane (i.e., lateral and anterior-posterior) than the amateurs in the downwards peripheral vision occlusion condition. Amateurs under auditory occlusion had significantly lower values of variability in the shoulder up-down movement variability.

Discussion

Several significant differences were found which will be summarized and discussed for the overall results. For that purpose, this section will be divided in two parts: i) comparing experimental conditions within each group; ii) comparing both groups on each experimental condition.

In the amateur group, significant differences were found on the variability of the shoulder up-down movements for the peripheral downward vision and both occlusion conditions compared to the no occlusion condition. A COD analysis revealed that the dribbling actions were significantly more stable in the up-down movements of the shoulder when peripheral downward vision was occluded. We may suggest that the lack of peripheral downward vision made them try to keep their shoulder stability to complete the task. When learning to dribble, players are often asked to keep their eyes off the ball and to low their centre of gravity, so it is probable that amateur players tried to stabilize their position as much as they could so, they would not impair their dribbling performance.

Still for the amateur players group, data revealed that under peripheral downward vision occlusion the elbow lateral movements had a significantly higher variability when compared to the no occlusion experimental condition (ApEn). This result indicates that in the lateral elbow movements, the lack of visual information regarding where the ball is during the dribble requires adaptive movements of the dribbler. Thus, the peripheral downward vision is a relevant perceptual information for the dribbling action in amateur players.

Observing the variability of the shoulder, elbow and wrist, the results seem to suggest that the elbow (on the lateral plan of movement) is responsible for the compensatory adaptive movements to maintain the dribbling action under visual occlusion conditions. So, contrary to what happened to the up-down movements of the shoulder, the lateral movements of the elbow showed signs of higher variability in the presence of visual occlusion. The increase of lateral elbow movement variability seems to be the novices' response to the lack of peripheral visual information, meaning that they are exploring joint elbow degrees of freedom to find other movement solutions to maintain the dribbling without visual information from the ball. Wrist lateral movement was significantly less variable when the individuals were in the no occlusion experimental condition when compared to both occlusion conditions (i.e., ApEn).

The lack of perceptual information impairs the individual-environment interaction, diminishing the quantity of perceptual information available to form the "global array" (Stoffregen & Bardy, 2001). So, it was expected, especially in the amateur group that variability values would be significantly different between conditions, since the ability to perform in sensory deprived contexts is often a criterion for success (Fajen et al., 2008).

Concerning the professional group, major significant differences were found when both peripheral downward vision and auditory were occluded compared to the no occlusion experimental condition. The shoulder lateral position displayed a tendency to increase variability in both occluded condition (i.e., visual and auditory) than in the no occlusion experimental condition. This suggests that both perceptual sources are relevant for the control of the dribbling action in high skill level players. Contrary to what was shown by the amateur group, the professional group responded to both occlusions (i.e., peripheral downward vision and auditory occlusion when together) with a more variable lateral shoulder movement, which represents torso movement and/or displacement of the overall body location on the frontal axis. The variability here shown should not be interpreted as "noise" (Buzzi, Stergiou, Kurz, Hageman & Heidel, 2003) and since it concerns to the professional group (i.e., where better performances are expected) we suggest that variability should be interpreted as an adaptive behavior in order to achieve task completion under the influence of external disturbances (Harbourne & Stergiou, 2009).

It is noteworthy that, for both groups, the movement adjustments (captured with an increase in the movement variability in specific plans of movement) under perceptual occlusions were performed by proximal joints, the shoulder and the elbow, whereas for the wrist (with more degrees of freedom) no differences were detected. This may suggest that the shoulder and the elbow adjust to each other (even in different plans of movement) to stabilize the movement of the wrist, an issue that requires further research.

So far it was shown that specific joints contribute to participants' movement adjustments during the dribble action under different experimental conditions. From now on, it will be discussed if the differences in the participants' skill level lead to differences in the movement variability between them, in other words we aimed to discuss the differences between amateurs and professionals.

In the wrist joint overall, data revealed that the amateur players had significantly higher variability during dribbling performance than professional basketball players. There was neither an axis nor a condition where significant differences were found to show that professionals performed the dribbling action with higher variability of the wrist than amateur players. Although Siegler (1996) stated that movement variability is higher in skillful individuals when compared to novices, in the current research we found that was the professional group who achieved the highest stability values for the wrist joint positions throughout the dribbling cycles. This was an expected result since the wrist joint can be described as an end-effector variable, which is the most distal joint in a movement that requires an interaction with an external body (e.g., a ball). Generally, motor coordination is achieved by the stabilization of the degrees of freedom in the end-effectors variables (Scholz & Schöner, 1999).

For the elbow anterior-posterior movements, amateur players displayed a higher variability than the professional players in all experimental conditions (i.e., see LyE). However, for lateral elbow movements, the professional players group showed a significantly greater variability (i.e., see COD and LyE) than amateurs under peripheral downward visual occlusion (i.e., peripheral visual occlusion and both occlusions). This suggests that high skilled basketball players increased elbow variability (in the lateral plan of movement) as a response to the need of perform a dribbling action under impaired experimental conditions, a behavior that could be interpreted as an adaptive, fitting right into Harbourne and Stergiou (2009) "flexible form to task completion" concept where in this case lateral elbow movement variability is a functional tool.

Although ApEn showed the opposite for the lateral elbow movement, it is possible that its behavior fits into a Pincus (1991) explanation stating that sometimes, in more complex movements, since the tendency to produce repeating patterns is lower, ApEn may not be the most suitable tool to assess variability. Richman and Moorman (2000) also addressed some discrepancy in ApEn values stating that under some conditions ApEn values tend to be biased.

For the up-down movements of the shoulder under the auditory occlusion condition, the amateur players showed a higher variability (i.e., see COD, ApEn and LyE) when compared with the professional group. This means that highly skilled players maintain the shoulder position more stable than the amateurs even under conditions where they cannot hear the sound of a bounce ball during the dribble. Therefore, results may suggest a decrease in the relevance of the auditory perceptual information with the increase of the player's skill level. Whereas for the lateral and anterior-posterior movements of the shoulder, under peripheral downward vision occlusion, the professional players showed significantly higher degrees of variability in the frontal and sagittal axis of movement, meaning that they responded to the peripheral downward visual occlusion with a greater lateral (i.e., COD and LyE) and anterior-posterior (i.e., LyE) shoulder movement variability than the amateurs to maintain the dribbling action. These results suggest that highly skilled players respond to an impaired visual condition increasing the shoulder horizontal movement variability (i.e., lateral and anterior-posterior). The specific joint movements' variability where professionals had a significantly higher variability than amateurs can be viewed as an adaptive mechanism. This means that highly skilled players explore other degrees of freedom to find other solutions to maintain the task completion under the lack of visual information from the ball, whereas the novices remain with similar movement solutions to maintain the consecutive dribbling. These results suggest an increase in the relevance of the ball downward visual information while dribbling with the increase of the player's skill level. With practice players become more attuned to the specific visual information from the environment. Thus, the increase on the relevance of ball peripheral downward visual information might be related with player's visual attunement (Fajen et al., 2008).

Conclusions

It is a reasonable assumption that professional basketball players have better dribbling performances than novices, so it is possible to pin point where does variability and stability might play a role for success in this task. Our results led us to conclude that the wrist joint movements of professional players have less variability than amateur players, under any experimental conditions. It was expected to be this way, being a joint in the end of a kinetic chain of a repetitive movement. Shoulder and elbow movements might have the answer to the research hypothesis raised on this study. When exposed to peripheral downward visual occlusion, professionals compensated an impaired perceptual context with greater elbow lateral movement variability as well with greater variability in shoulder lateral and anterior-posterior movement, to, theoretically keep the stability of the movements of the joints closest the ball. We may conclude that the higher ability of professional basketball players to stabilize wrist movement is accompanied by a greater variability in the horizontal movements of the shoulder (i.e., left-right; back-forth) and in the lateral movements of the elbow, especially under downwards peripheral vision occlusion.

Due to sample size, these results should be interpreted with caution, and, although data is fairly consistent throughout the study, further research is needed to strength these findings.

Article 2

Are synergies formed on cyclical continuous movements? An example with the basketball dribble task.

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Abstract

In human movement, synergies occur when two variables co-vary to stabilize a performance goal. On a kinetic chain of movement, two proximal joints might reciprocally compensate to stabilize an end-effector joint. End-effector variables are conscientiously 'controlled', and directly linked to performance, whereas the task relevant elements, are allowed by the system to have high variability, providing adaptability. In basketball dribbling, we hypothesized that shoulder and elbow variability contributes to stabilize the dribble height as an end-effector performance variable. Uncontrolled Manifold was used to capture synergies. Results identified synergies formation during basketball dribbling, which only occurred when the wrist reached its peak height. The control of the wrist peak height, is achieved due to a reciprocal compensation between shoulder and elbow which stabilizes the dribbling height.

Keywords

Uncontrolled Manifold; Basketball Dribble; Synergies; Motor Control

Introduction

Since Bernstein studies in motor control in 1967, the notion of degrees of freedom was created and has been widely accepted. The concept consists in recognizing that each joint has several degrees of freedom which provide the human body with an infinite number of movement possibilities when combining multiple joints. For a specific motor task, the finite number of constraints of the human movement system is the cause for the infinite number of solutions for a given task (Klous, Danna-dos-Santos & Latash, 2010). Scholz and Schöner (1999) suggested that there is a finite number of degrees of freedom that can be "controlled", which means that there is a significant amount of degrees of freedom that are "uncontrolled". Bernstein (1967) indirectly suggested that there were uncontrolled aspects in the coordination of functional motor tasks, where only spatial aspects of movement represented by the end-effector variables (i.e., distal joint) were controlled rather than all the specific actions of joints or muscles that culminated in the end-effector joint movement.

Scholz and Schöner (1999) developed a method to test which degrees of freedom were "controlled" and "uncontrolled" by assessing joint position stability. The authors claimed that any real movement is constantly disturbed by a plethora of constraints, and that stability in this "control-theoretical sense" is pivotal for a successful task completion. Motor coordination is achieved by stabilizing some degrees of freedom, which means that while performing there are variables that should remain stable, especially the distal joints when movement requires interaction with an external body/object (i.e., Scholz and Schöner describe them as end-effector variables) (e.g., the dominant hand in basketball dribble). In this situation, other variables may (should) vary without affecting the task output, or in other words, to stabilize the task output. The first group of variables, those that should remain stable, were called by Scholz and Schöner primary variables, whereas the second group of variables, those that are supposed to vary, were named secondary variables (Scholz & Schöner, 1999). The authors suggested that the difference of stability between the primary and secondary variables may be a manifestation of how the nervous system controls movement, which highlights the complementary nature between stability and variability in the coordination of movements (Scholz & Schöner, 1999; Kelso & Engström, 2006).

Stability in end-effector variables is crucial for a successful task and these are the (primary) variables that should be considered to be "controlled", hereinafter called ‘performance variables’. The secondary variables may vary more or less, and fall into the spectrum of variables that are not consciously controlled, hereinafter called ‘task relevant elements’.

The *uncontrolled manifold hypothesis* (UCM) helps us to understand how this complementarity between variability and stability might work. If we analyzed all the joints angles that contribute for a particular movement we could divide them into two orthogonal axes: one, where the variance of the joint angles would affect the end-effector stability, and another, where the variance of the joint angles would not affect end-effector stability. This second axis consists on joint configurations that somehow do not affect performance negatively.

The task relevant elements, those variables that do not affect the stability of the performance variable, define the subspace called the *uncontrolled manifold* (UCM) (Scholz & Schöner, 1999). The authors theorized that the UCM basically consists on joint angles that co-vary to keep the end-effector performance variable invariant. The UCM provides a movement system with the ability to adapt to a potential disturbance that could induce an error to the expected output in a way that task elements change to minimize the potential error with no need of a consciously corrective action from the individual (Latash, Scholz & Schöner, 2002).

The movement system allows high variability values to its task elements as long as it does not affect the “controlled” performance variable value. The UCM represents the “less controlled” elements which give to the movement system more freedom while staying in a subspace where they do not affect negatively end-effectors elements (Latash, Scholz & Schöner, 2002). This higher variability allows the system to remain variable and still able to attain its goals even when exposed to unpredictable external forces and inherently noisy elements. However, Hasan (2005) suggested that stability may not be always desirable since it implies a trade-off with variability. This means that stability must be pursued to specific variables at a specific time along a trial, but not to all variables, implying that the complementary nature between stability and variability is the key to successful coordinated movements (Kelso & Engström, 2006). When it comes to UCM subspace, task elements variability that disturbs the stability of performance variables is restricted, but variability values in the range within which performance variables stability remains unaffected are allowed (Riley et al., 2011).

The term synergy was created to explain the relationship between the specific variability of task relevant elements to provide a desired stability of an important output, a performance goal (expressed with a performance variable) (Latash, 2010), for instance to maintain a dribbling action. Succinctly, a synergy can be assessed using the concepts of “good” variance and “bad” variance. The first does not disturb the performance goal stability, whereas the second does (Latash, 2010). Riley et al. (2011) used the term “reciprocal compensation” to describe the ability of a system component to adjust itself to react to the other components changes.

Since “good” variance does not affect the performance goal values, this could be interpreted as irrelevant. However, several studies (Gorniak, Zatsiorsky & Latash. 2007; Shapkova et al. 2008; Zhang et al. 2008) already showed that “good” variance does not disturb a specific performance goal, but it affords the movement system variability to perform other tasks using the same task relevant elements and, potentially, to deal with unexpected perturbations applied to one of the task elements (Latash, 2010).

Synergistic control is not inherent to all natural human movements, and it can be learned and modified (Latash, 2010). For that reason, in sports related complex movements, one can expect to find synergies since skilled performers are not locked into rigidly stable solutions (coordination patterns), but rather can modulate their behaviours to achieve consistent performance outcome goals (Araújo & Davids, 2011).

In sports performance movement variability has been distinguished as one very important issue for adaptation and, consequently, success (Pinder, Davids & Renshaw, 2012). For instance, in basketball dribbling, we hypothesized that shoulder and elbow variability may contribute to stabilize the dribble height as an end-effector performance variable. Furthermore, we hypothesized that synergies formation may occur and differ along the dribbling action. This hypothesis was sustained on a previous study by Black, Riley and McCord (2007) who analyzed intra- and interpersonal rhythmic limb coordination and found out that synergy values changed during the movement cycle. The authors noted that synergies seemed to be ‘stronger’ at the end-points of the movements’ cycle, suggesting that in those positions the movement might be more perceptually significant. Consequently, the adjustments to be made would be easier to do when the movement velocities approached zero (i.e., the end-points) rather than in the mid-cycle (Black, Riley & McCord. 2007).

Thus, we aim to verify if there is synergies formation during the performance of the basketball dribble. And if so, if there are differences in synergies formation during the up-and-down movement cycle or just part of it. Getting inspiration from Black and colleagues (Black et al, 2007), synergies formation was analyzed at the end-points of the basketball dribble movement cycle, that is when the dribble reached its highest and its lowest height.

Materials and Methods

Participants

The study had twenty participants assigned to two groups according to experience level: an amateur group and a professional group. The amateur group included ten grad-students (6 men, 4 women) in sport sciences with no competitive experience of basketball. Resembling to contemporary studies (e.g., Sholz & Schöner, 1999; Klous, Danna-dos-Santos & Latash, 2010; Romero, Kallen, Riley & Richardson, 2015), we opted to use both genders. The age of the participants ranged between 18 and 26 years old (Mean = 19.4, SD = 2.9). To be included in the professional group, the participants needed to have at least 3 years of playing experience of basketball and to play in a team placed on the top 2 national leagues. The professional group also included ten athletes (8 men, 2 women). The age of the participants ranged between 18 and 31 years old (Mean = 23.3, SD = 3.8).

The sample size was estimated using F-tests (ANOVA, Repeated Measures, Between Factors) for 2 groups and 2 measurements, with a large effect size of 0.60, an alpha error probability of 0.05, a beta error probability of 0.20 (i.e., a power of 0.80), and a correlation among measures of 0.50, which provided a total sample size of 20 subjects (e.g., a sample size per group of 10 subjects). This procedure was performed using the GPower software (Universität Düsseldorf, Germany).

All the participants were voluntary and signed an informed consent form. The Ethics Committee of the Faculdade de Motricidade Humana, Universidade de Lisboa approved the study that was conducted according to the principles expressed in the Declaration of Helsinki.

Experimental Task

The participants were asked to execute a single trial of 42 consecutive dribbles in basketball with the dominant hand in a stationary position (i.e., without locomotion). Prior to task performance, the participants were informed with standardized task instructions about the experimental procedures.

Facilities and Materials

The experimental setup was assembled in an indoor laboratory room. The basketball ball (size 7) is in accordance with the official FIBA measures. The following tools were also used: four spherical reflective markers to be placed in the third metacarpal epiphysis of the dominant hand, on the wrist, elbow and shoulder of the same side; double-sided adhesive tape (to fixate the reflective marker).

Experimental Setup

The three-dimensional (3D) participant's movement while dribbling was captured with a sample frequency of 120 Hz (Motive 2.1.1 by Optitrack©). For that purpose, six Prime 13 by Optitrack© cameras were used. Motive software recorded the 3D coordinates (i.e., sagittal axis, frontal axis and longitudinal axis) of the marked points. The time series were then exported as csv files. Finally, MATLAB (version R2019a) routines were used to analyse the 3D coordinates of the marked points and to calculate the dependent variables required to analyse the dribbling action.

Synergies assessment

Synergies quantification was calculated with the *uncontrolled manifold* (Scholz & Schöner, 1999). The hypothesis that shoulder and elbow angles stabilize wrist height as a performance variable can be demonstrated by the computation of two quantities (Black et al., 2007): (i) the compensated variance (i.e., the variance along the UCM that contributes to stabilize the performance variable); (ii) the uncompensated variance (i.e., the variance that does not contribute to stabilize the performance variable). The compensated variance, in this study, expresses the reciprocal compensation between two angles to stabilize the dribbling height.

The relation between the compensated and uncompensated variance was expressed with a ratio of UCM (i.e., UCM = $\text{var}_{\text{comp}}/\text{var}_{\text{uncomp}}$) that represents the existence or not of synergies. Thus, UCM values are used to quantify functional synergies: if the UCM value is larger than 1, then a synergy exists; if the UCM value is smaller than 1, then there is no synergy (Latash, 2010; Passos, Milho & Button, 2017).

Assessment of UCM was defined for trials with 40 consecutive dribbles (excluding the first and last one) at two moments of each movement of the dribbling cycle: (i) when the wrist reaches its peak height called 'UCM Up'; (ii) when the wrist reaches its lowest height called 'UCM Down'. The identification of these moments within the discrete time series of the captured 3D coordinates was defined using a data analysis that detects the maximum and minimum values of the height coordinate of the wrist. For this purpose, a MATLAB routine was developed based on the function *findpeaks* which allowed the identification of 40 local maxima and 40 local minima within discrete data series. For the identified time series values, the corresponding 3D coordinates were extracted and considered for the calculation of both UCM Up and UCM Down.

A Jacobian matrix is required for the UCM calculation, describing how small changes in the output of the shoulder angle and elbow angle echoes in the magnitude of the wrist height. To define the Jacobian matrix, a rigid body model was used to represent the relative position of the upper arm and forearm in the 3D space, presented in Figure 1 at a generic position configuration. The shoulder, elbow and wrist are considered 3D points representing the anatomic joints centre. Rigid line segments were used to represent: (i) the upper arm (i.e., from the shoulder to the elbow), and (ii) the forearm (i.e., from the elbow to the wrist). The playing floor is parallel to the XY plane and reference axis Z is related to the height direction.

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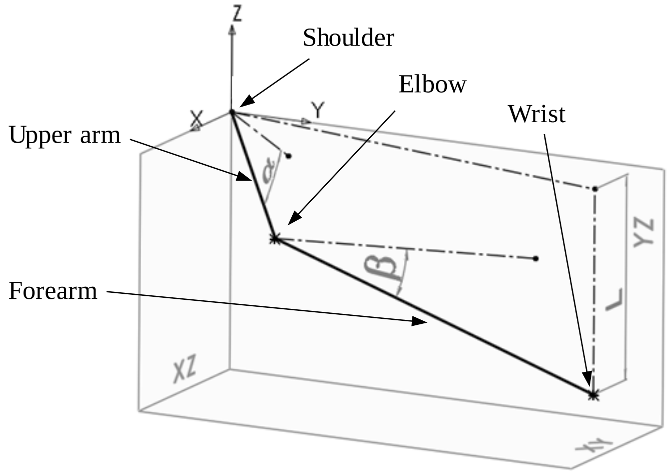

Figure 1. Upper arm and forearm model in a generic position configuration.

The task relevant elements were defined as shoulder angle α and elbow angle β. These angles were defined between the rigid line segments and their projections onto planes parallel to plane XY passing through shoulder and elbow points, respectively for the upper arm and the forearm. The performance variable was defined as the wrist height L, corresponding to the vertical distance along axis Z between wrist and shoulder. Based on this kinematic model, the response of the wrist height with respect to the shoulder given as an output of the shoulder angle and elbow angle was described by

$$L = l_{upper\ arm} \cdot \sin(\alpha) + l_{forearm} \cdot \sin(\beta) \tag{1}$$

where $l_{upper\ arm}$ and $l_{forearm}$ are the rigid segments lengths of the upper arm and forearm, respectively. The length of each segment was calculated based on the 3D coordinates of the proximal and distal joint of each segment. Based on the coordinates of the shoulder $(x,y,z)_s$, elbow $(x,y,z)_e$ and wrist $(x,y,z)_w$, the segments lengths were given by

$$l_{upper\ arm} = \sqrt{(x_s - x_e)^2 + (y_s - y_e)^2 + (z_s - z_e)^2} \tag{2}$$

$$l_{forearm} = \sqrt{(x_e - x_w)^2 + (y_e - y_w)^2 + (z_e - z_w)^2} \tag{3}$$

Therefore, the corresponding Jacobian matrix **J** was given by the partial derivatives of the performance variable with respect to the task relevant elements, such that

$$\mathbf{J} = \begin{bmatrix} \frac{\partial L}{\partial \alpha} & \frac{\partial L}{\partial \beta} \end{bmatrix} = [l_{upper\ arm} \cdot \cos{(\alpha)} \quad l_{forearm} \cdot \cos(\beta)] \tag{4}$$

The Jacobian matrix evaluated at the reference configuration $\mathbf{J}^0$, allows to estimate the response of the performance variable, such that

$$L^t - L^0 = \mathbf{J}^0 . \begin{bmatrix} \alpha^t - \alpha^0 \\ \beta^t - \beta^0 \end{bmatrix} \tag{5}$$

where the superscript *t* refers to each time corresponding to the 40 moments when wrist height is maximum or minimum and the superscript *0* refers to the reference configuration state estimated by averaging the values of α, β and L for all the previously identified 40 moments of the dribble cycle.

This methodology estimates compensated and uncompensated variances associated with directional deviations on the UCM subspace, which was approximated to the null-space of the Jacobian matrix representing the combinations of shoulder and elbow angles not affecting the height of the wrist. A corresponding basis vector of the null-space allows to resolve a vector of the shoulder and elbow deviations from the reference configuration into its parallel and perpendicular projections onto the UCM subspace and estimate the variance in each of the subspaces var_{comp} and var_{uncomp}, such that the quantification of the synergies was obtained by the ratio *UCM* given by

$$UCM = \frac{var_{comp}}{var_{uncomp}} \tag{6}$$

which was evaluated for both moments of the dribble cycle (i.e., the highest height and the lowest height), with corresponding ratios UCM Up and UCM Down.

Statistical Procedures

The first procedure consisted on computing the mean values and standard deviations for each variable (UCM Up and UCM Down) and each group (novices and professionals). Next, the normality and the equality of variances conditions of both variables and both groups were tested using Shapiro-Wilk’s tests and Levene’s tests, respectively. Subsequently, a Two-Way ANOVA for Repeated Measures and Two Groups was performed to evaluate the difference between the mean values of both variables and both groups, as well as to check the existence of interaction. The probability of 0.05 was set as the criterion for statistical significance. This statistical analysis was undertaken using the IBM SPSS software (version 25, IBM Inc., USA).

Results

For the 20 participants under study, UCM values above 1 were found for 17 of them when the dribbling achieved its highest peak (UCM up), which revealed the existence of synergies. In contrast, 17 out of the 20 participants displayed UCM values below 1 for the dribbling lowest height (UCM down), which it is not consistent with the existence of synergies (Table 1).

For participant 9 of the amateur group, the UCM Up value was substantially larger ($\text{UCM Up}_{(9)} = 14.94$) than all the other subjects’ UCM Up values which biased the mean and compromised the normality condition. Therefore, this participant values were temporarily removed from the files for statistical purposes. As previously mentioned, a preliminary study provided the mean values and standard deviations of each variable in each group (Table 1). Then, the normality and the equality of variances conditions were verified for both variables in both groups. Finally, the Two-Way ANOVA revealed that: (i) there was no interaction effect ($F_{(1,17)} = 0.01$, $p = 0.95$, $\eta_p^2 = 0.00$); (ii) there were significant differences with large effect size between UCM Up and UCM Down values ($F_{(1,17)} = 24.48$, $p < 0.01$, $\eta_p^2 = 0.59$); (iii) there were no significant differences between novices and professionals ($F_{(1,17)} = 0.46$, $p = 0.51$, $\eta_p^2 = 0.03$).

Table 1. UCM Up and UCM Down values for the highest and lowest height of the basketball dribbling movement cycle in amateurs and professionals.

	UCM Values	
	UCM Up	UCM Down
Amateur group		
1	0.90	0.66
2	**1.10**	0.20
3	**1.79**	0.29
4	**2.86**	0.39
5	**1.19**	0.04
6	**1.42**	0.49
7	**2.31**	0.13
8	**4.90**	0.49
10	**4.34**	0.87
Mean±SD	2.31±1.45	0.40±0.26
Professional group		
1	**1.64**	**1.36**
2	**6.51**	**1.04**
3	0.54	0.68
4	**1.22**	0.39
5	**3.14**	0.89
6	0.63	0.20
7	**3.06**	0.98
8	**5.02**	0.40
9	**3.02**	0.65
10	**1.04**	0.55
Mean±SD	2.58±1.98	0.71±0.35

Note: UCM values represent the ratio var_{comp}/var_{uncomp} when the dribble reaches its peak height (UCM Up) and when it reaches its lowest height (UCM Down). UCM values are used to quantify functional synergies: if UCM > 1, then a synergy exists; if UCM < 1, then there is no synergy.

In sum, the statistical tests showed that UCM Up values were significantly different from UCM Down values, decreasing from the wrist highest height to the wrist lowest height. This suggests that the UCM changes significantly during the same movement cycle, reaching the largest values in the wrist highest position.

Discussion

The movement cycle synergy has been addressed by authors (Black et al., 2007; Fuchs & Kelso, 1994; Schmidt & Turvey, 1995) as a cycle where the amount of variability within the UCM was not uniform during the movement. The main reason to assess UCM values when the wrist reached its peak height and its lowest height was due to the fact that higher ratio values are expected at the end-points of a movement cycle (Black et al., 2007). This may happen because the degrees of freedom are more perceptually relevant at this point (Bingham, 2004), or because it may exist a tendency for synergies formation when the movement velocities approach zero since the adjustments to stabilize the performance goal (e.g., to keep the dribble under control) seems 'easier' to achieve (Black et al., 2007).

The results of this study show that synergies were formed when the wrist reached its peak height when dribbling, contrary to what happened at the wrist lowest height. The difference between the two moments' mean values was statistically significant with large effect size and the arguments that might justify this outcome are bellow.

Basketball dribble implicates a perception and action coupling between the participant and the ball and, for that, haptics plays a relevant role since vision is rather used to control environmental aspects of the game itself. So, the individual leans on the proprioceptive and haptic systems to get perceptual information about the movement that is being executed. Although the proprioceptive system is always active during the movement, the haptic system has moments when it does not receive any information about the ball, e.g., as soon as the ball leaves the hand towards the floor and then returns to the hand there is a haptic information gap. The moment when the wrist reaches its lowest height, the ball is out of the individual hands (i.e., approximately the moment when the ball hits the ground), which means there is lack of perceptual information when compared to the moment when the wrist reaches its peak height. At the peak height, the hand is in permanent contact with the ball and the vertical velocity up to a certain point must be approximately zero, due to the required deceleration of the ball when it reaches the peak height of the movement cycle, contrary to what happens when the wrist reaches the lowest height and the ball is stopped by hitting the floor. Furthermore, at the wrist peak height, the task constraint to stop the ball mid-air to re-initiate the movement cycle requires behavioural adjustments of the dominant limb, whereas a reciprocal compensation between shoulder and elbow angle to stabilize the wrist height seems to exist. This reciprocal compensation was captured for UCM Up values above 1, which suggests synergies formation between shoulder and elbow angles to stabilize the dribble height. Although the velocity of the movement is also approximately zero when the wrist reaches its lowest height, the individual does not have haptic perceptual information because he/she is not in physical contact with the ball. This temporary lack of perceptual information may cause limitations on behavioural adjustments between shoulder and elbow angles to stabilize the lowest dribbling height. Moreover, we may also suggest that due to an almost complete extension of the arm these adjustments are unnecessary at this stage of the dribbling action, which means that the dribbling control is based on proprioceptive and predictive information (i.e., the expected linear up-and-down path of the ball).

Performance depends on the previous knowledge about the situation, as well as on the adjustments made during the execution which are heavily influenced by the array of perceptual information available (Messier & Kalaska, 1999).

Intercepting a moving object forces the individual to predict its future position, especially if the visual information is lacking. Haptic and proprioceptive systems can help to compensate the absence of visual information (Stoffregen & Bardy, 2001), but what this study showed is that the amount of perceptual information available influences synergies formation on the basketball dribbling task.

Article 3

Differences on wrist trajectories in a basketball dribbling task under different perceptual setups – Professionals vs. Amateurs

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Abstract

Previous researches identified wrist position as a performance indicator on a static basketball dribbling task performance. Following the perceptual occlusion paradigm, we opted to better understand a specific contribution of a perceptual source for this specific task motor control by occluding it and identifying the consequent adaptive joint behavior. Since peripheral vision and auditory perceptual information are often constrained in a basketball competitive situation we decided to quantify the impact that both of these perceptual sources occlusion had on dribbling performance within and between two groups (i.e. amateurs and professionals). Wrist vertical position was chosen as a performance indicator. In order to quantify differences on performance values, dissimilarity was measured using a Procrustes analysis allowing to precisely identify the evolution of wrist vertical position over time enabling to compare dissimilarity means between conditions and groups. Peripheral vision occlusion disturbed amateurs dribbling performance almost four times more than professionals, however auditory occlusion did not affect neither, amateur nor professionals' performance. There were not cumulative effects on performance when the individual was subjected to both occlusions at the same time.

Keywords

Dissimilarity; Performance; Basketball Dribbling; Perceptual Information; Motor Control

Introduction

Basketball dribbling, as other sport skills, is constantly being influenced, in a competitive setup, by spatial, temporal and individual constraints, which demands a continuous adaptive behaviour (Chow et al., 2008). However, basketball dribbling poses new challenges to assess. This particular skill possesses a cyclical nature, being composed by a sequence of constant interceptive relations between the hand and the ball that is inherently perceptually intermittent. The inability to reproduce skill executions due to intrinsic factors (e.g. biological systems inability to reproduce exactly the same movement patterns (Bernstein, 1967)) and extrinsic factors (e.g. task constraints, environmental constraints) suggest that this cyclical movement has to be adaptive.

The individual is dependent on his perceptual sources to actively explore environmental and task related information in order to, through feedback information, adapt its behaviour during execution (Chow et al., 2008). On a previous research, joint variability values were assessed for a static basketball dribbling task (i.e. no displacement of the individual) in order to find out what elements of the dominant harm displayed a better adaptive behaviour (Robalo et al., 2020). Results showed how the manipulation of perceptual variables caused an increased joint movement variability on shoulder horizontal movement and on elbow lateral movement, which was interpreted as an adaptive behaviour. Moreover, this adaptive behaviour seems to be a performance indicator since professional players displayed significantly higher values of variability than amateurs. Although shoulder and elbow variability was key feature for professionals players' behaviour, the wrist position displayed a greater stability throughout all perceptive occlusion conditions for this high level players (Robalo, Diniz, Fernandes & Passos, 2020). Consequently, wrist vertical position asserted itself as performance factor. The arguments to support this assumption are: i) wrist position variability was lower when amateurs had no perceptual source occlusion compared to the occluded conditions; ii) when comparing both groups, wrist position stability was higher for professionals throughout all conditions; iii) wrist vertical position was stabilized by a shoulder/elbow synergy (Robalo et al., submitted).

Following the same reasoning, we aim to asses if perceptual occlusion disturbed the end-effector (i.e., the wrist) cyclicality on a basketball dribbling task, and how experience level influenced overall results. The cyclicality of the dribbling task can be illustrated by the wrist vertical trajectory of the dominant hand, as a performance indicator. Thus, the analysis of wrist vertical trajectories in a Cartesian space helped us to quantify hypothetical dribbling performance differences throughout groups and conditions. The dissimilarity between trajectories may be a sign of adaptive behaviour due to level of experience or change in practice conditions.

Quantifying trajectories dissimilarity was previously used to measure the difference in movements between two performance scenarios (Passos, Campos & Diniz, 2017). In this study, we aimed to assess the relevance of visual and auditory perceptual sources on basketball dribbling performance. For that purpose, the wrist trajectory of the dominant harm was used as a performance indicator. Trajectories assessment allowed to continuously assess wrist vertical position along the performance of consecutive dribbles. The trajectories dissimilarity, on several experimental conditions was measured with a Procrustes analysis. This method allowed to accurately quantified how different trajectories were, making it possible to identify how impactful was the occlusion of a specific perceptual occlusion on performance, and as such capturing an adaptive behaviour.

Perceptual Information for Dribbling Control in Basketball

How relevant is a specific perceptual source to control a specific sports movement is an important question, to which the answer depends on the specificity of the sports movement that is being analysed. Heinen and Vinken (2001) suggested studying the contribution of perceptual sources in motor control research through occlusion, investigating how much of an impact does an occlusion of a perceptual source has on movement execution.

Although the authors discovered how important was visual information in a gymnastics handspring on vault task, the physical characteristics of the tool comparing to a ball (i.e. tool used for dribbling) are completely different. Motor control issues on a constantly moving, perceptual intermittent (i.e. when dribbled) tool, such as the ball, is yet to be studied. Dribble is a cyclical interceptive task, in which the position of the tool (i.e., ball) changes due to the individual action, posing a constant perceptual challenge where, not only perceptual information might contribute, but also the ability to anticipate ball position based on prior knowledge (Mazyn et al. 2007; Scaleia et al. 2015; Nijhawan & Wu, 2009).

Fajen and colleagues (2008) highlighted the importance of perceptual information for adaptive behaviour stating that “perceptual attunement to different informational variables as conditions change” (Fajen et al., 2008, pp.85). The authors characterize the optimization of optical, auditory, haptic and proprioceptive information as sign of perceptual learning towards convergence, which they identify as attunement. This optimization will allow individuals to thrive in perceptual deprived environments, being a criterion for performance success (Bennet et al., 1999; Stoffregen & Bardy, 2001). The process consists, theoretically, on the compensation of the lack of information from a perceptual source with a better drive onto the search of available relevant information by the unconstrained sources. Although Bennet and colleagues (1999) remained sceptic if visual information deprivation could be fully replaced with the other sources contribution, as Heinen and Vinken (2001) demonstrated using the gymnastics handspring on vault task, this possibility might be task specific since for professional level basketball players, in a static dribbling task (i.e. no overall displacement of the individual), performance was not affected by downwards peripheral visual occlusion when compared to a no occlusion condition (Robalo et al., 2020).

In order to make our static basketball dribbling task as representative as possible we opted to impair the perceptual sources that are, generally, occluded during a competitive situation. During a competitive match a skilled ball carrier focus its attention on the environmental aspects of the match (e.g. teammates position, opponents’ movement) (Maurer & Munzert, 2013). Auditory information is obstructed by the interference of the crowd noise on what could be useful information to control the dribble. Nevertheless, skilful athletes can maintain this type of dribble under control most of the time, making us wondering how relevant are these perceptual sources to control it.

Quantifying dissimilarity

Quantifying movement differences between two scenarios poses a methodological challenge which the literature does not offer a vast number of methods to solve (Passos et al., 2017), and although qualitative analysis if often used to compare data obtained in a quantitative fashion, this process lacks the ability to answer one simple question – how much different are two scenarios? Procrustes analysis is a powerful mathematical method that helps us answer this question. Quantifying moving trajectories dissimilarity is particularly useful to assess precisely movement performance, which is key to sports performance, motor rehabilitation or even medical surgical contexts (Passos et al., 2017).

In the particular task analysed in this study (i.e. static basketball dribbling) scenarios were divided by level of experience (i.e. amateurs and professionals) and type of occlusion (i.e. no occlusion, peripheral vision occlusion, auditory occlusion, both occlusions). Being visual and auditory perceptual information situation specific, reciprocally influencing the context (Gibson, 1979) we tried to identify if experience might influence the need of a specific source attentional focus to perform the task. We aim to quantify occlusion impact in both groups performance. The ability to display lower dissimilarity values between conditions represents a lower impact on performance.

No parallelisms can be established between dribbling motor control and other tasks, not only because motor aspects and perceptual aspects of control are task specific, but also because the unique features of dribbling skill consist on a constantly interceptive, perceptually intermittent execution.

Dribbling Performance

Regarding basketball dribbling, wrist position variability in a static dribbling task was significantly lower for professional athletes when compared to amateurs (Robalo et al., 2020) which was predictable due to the fact that the wrist is in the end of the kinetic chain of the movement (Bernstein, 1967; Scholz & Schöner, 1999). In the same study, higher levels of variability of lateral elbow movement and horizontal shoulder (i.e. lateral and anterior-posterior) movement were observed in professionals which, once again, confirmed theoretical expectations given by theory that systemic properties to maintain stability in the end-effector joint while allowing variability in the other joints confers the system the ability to perform successfully while maintaining its flexibility to adapt to constraints (Scholz & Schöner, 1999). The fulfilment of these expectations contributed to the thought that these differences could represent a better adaptive behaviour by the professionals.

Materials and Methods

Participants

The study had twenty participants assigned to two groups according to skill level: an amateur group and a professional group. The amateur group included ten grad-students (6 men, 4 women) in sport sciences with no competitive experience of basketball. Resembling to contemporary studies (e.g., Scholz & Schöner, 1999; Klous, Danna-dos-Santos & Latash, 2010; Romero, Kallen, Riley & Richardson, 2015), we opted to use both genders individuals. The age of the participants ranged between 18 and 26 years old (mean = 19.4, SD = 2.9). To be included in the professional group, the participants needed to have at least 3 years of playing experience of basketball and to play in a team placed on the top 2 national leagues. The professional group included ten athletes (8 men, 2 women). The age of the participants ranged between 18 and 31 years old (mean = 23.3, SD = 3.8).

The sample size was estimated using F-tests (ANOVA, Repeated Measures, Between Factors) for 2 groups and 6 measurements, with a large effect size of 0.50, an alpha error probability of 0.05, a beta error probability of 0.20, and a correlation among measures of 0.50, which provided a total sample size of 20 subjects (e.g., a sample size per group of 10 subjects). This procedure was performed using the GPower software (Universität Düsseldorf, Germany).

All the participants were voluntary and signed an informed consent form. The Ethics Committee of the Faculdade de Motricidade Humana, Universidade de Lisboa approved the study that was conducted according to the principles expressed in the Declaration of Helsinki.

Experimental Task

The participants were asked to execute successfully four trials of 42 consecutive dribbles in basketball with the dominant arm in a stationary position (i.e., without locomotion). Each participant performed one trial under each of the following experimental conditions: i) dribbling with no occlusion (NO); ii) dribbling with visual occlusion (VO); iii) dribbling with auditory occlusion (AO); iv) dribbling with both visual and auditory occlusion (BO). The sequence of these four experimental conditions was randomly selected for each individual.

In the first condition (i.e., dribbling with no occlusion), the participants were asked to perform a dribbling action in basketball without occluding any perceptual source; in the second condition, the participants were asked to perform the basketball dribbling action with occlusion goggles which inhibits downwards peripheral vision, preventing the participant to capture visual information from the ball while performing the dribbling action; in the third condition, the subjects were asked to perform the basketball dribbling action using headphones that totally prevent the participant to receive auditory information related to the bouncing ball while performing the trial; in the fourth condition, the subjects were asked to perform the basketball dribbling action with both perceptual sources simultaneous occluded, the peripheral vision (using the occlusion goggles) and the audition (using the headphones), which prevents the participants to capture visual and auditory information while performing the basketball dribbling action. Prior to task performance, the participants were informed with standardized task instructions about the experimental procedures regarding the visual and auditory occlusion.

The experimental setup was assembled in an indoor laboratory room. The basketball ball (size 7) is in accordance with the official FIBA measures. The following tools were also used: one spherical reflective marker to be placed on the wrist; double-sided adhesive tape (to fixate the reflective marker); a pair of goggles to occlude downwards peripheral vision; a set of headphones Beats by Dre© to isolate external noise and a mp3 player to play a continuous white noise sound to block out any external sound information.

The three-dimensional (3D) participant's movements while dribbling was captured with a sample frequency of 120 Hz (Motive 2.1.1 by Optitrack©). For that purpose, six Prime 13 by Optitrack© cameras were used. Motive software recorded the 3D coordinates (i.e., sagittal axis, frontal axis and longitudinal axis) of the marked point. The time series were then exported as csv files. Finally, MATLAB (version R2019a) routines were used to analyse the 3D coordinates of the marked points and to calculate the dependent variables required to analyse the dribbling action.

All possible paired combinations between the four experimental conditions (i.e., NO, VO, AO, BO) were used as independent variables (i.e., VONO, VOBO, VOAO, AOBO, BONO, AONO). The vertical position of the wrist, more precisely, the dissimilarity between vertical positions was used as dependent variable.

Procrustes Method

The dissimilarity between each pair of vertical trajectories was identified using an original routine implemented in MATLAB (version R2019a) based on the Procrustes Method, in which each pair of possible conditions graphics were mathematically overlapped and matched in order to find the dissimilarity value along the 42 dribbles. The Procrustes Method is a mathematical procedure for relating two shapes, grounded on finding a linear transformation (scaling, rotation, reflection, and translation) of the points in one shape to best match them to the points in the other shape. The dissimilarity measure between the two shapes is the minimized value of the sum of squared deviations, standardized by the sum of squared elements of the mean centered target shape. The value of the dissimilarity measure varies between 0 and 1, or 0% and 100%, with a value of 0% reflecting strong shape similarity and a value of 100% representing strong shape dissimilarity. This geometrical methodology has been widely used to obtain the dissimilarity between human trajectories, namely, between arm movements in real and virtual scenarios (Passos, Campos, & Diniz, 2017). In this particular case, due to cyclical nature of the dribbling movement, dissimilarity values between each pair of trajectories were obtained over moving windows of length $L = 100$ (which resembles the mean length of the dribbling cycles) and the corresponding mean was then obtained.

Statistical Procedures

The first step of the statistical analysis consisted on determining the mean values and standard deviations of the dissimilarity for each paired conditions and each group. Next, Shapiro-Wilk’s and Mauchly’s tests were used to examine the normality and the sphericity conditions, respectively, of the dissimilarity. Subsequently, a mixed ANOVA for Repeated Measures and Two Groups (with Bonferroni’s post-hoc comparisons) was performed to evaluate the difference between the mean values of the paired conditions and the groups, as well as to check the existence of interaction. Since the sphericity condition was not validated, the test for the repeated measures (within-subjects) was undertaken with the Greenhouse-Geisser correction. Finally, some independent samples t-tests and paired samples t-tests were performed in order to identify the specific origin of the observed differences. The probability $p < .05$ was set as the criterion for statistical significance. This part of the study was undertaken using the IBM SPSS software (version 25, IBM Inc., USA).

Results

A plethora of results emerged from this analysis and we highlighted the most relevant ones to answer our research questions.

Figure 1 illustrates, for participant S6, the Procrustes method applied to the pair of trajectories regarding the vertical movements of the wrist in the VO and NO conditions. In this particular situation, the obtained mean dissimilarity value d was 0,233 %. Table 1 presents the mean values and standard deviations of the dissimilarity values for each paired conditions and each group.

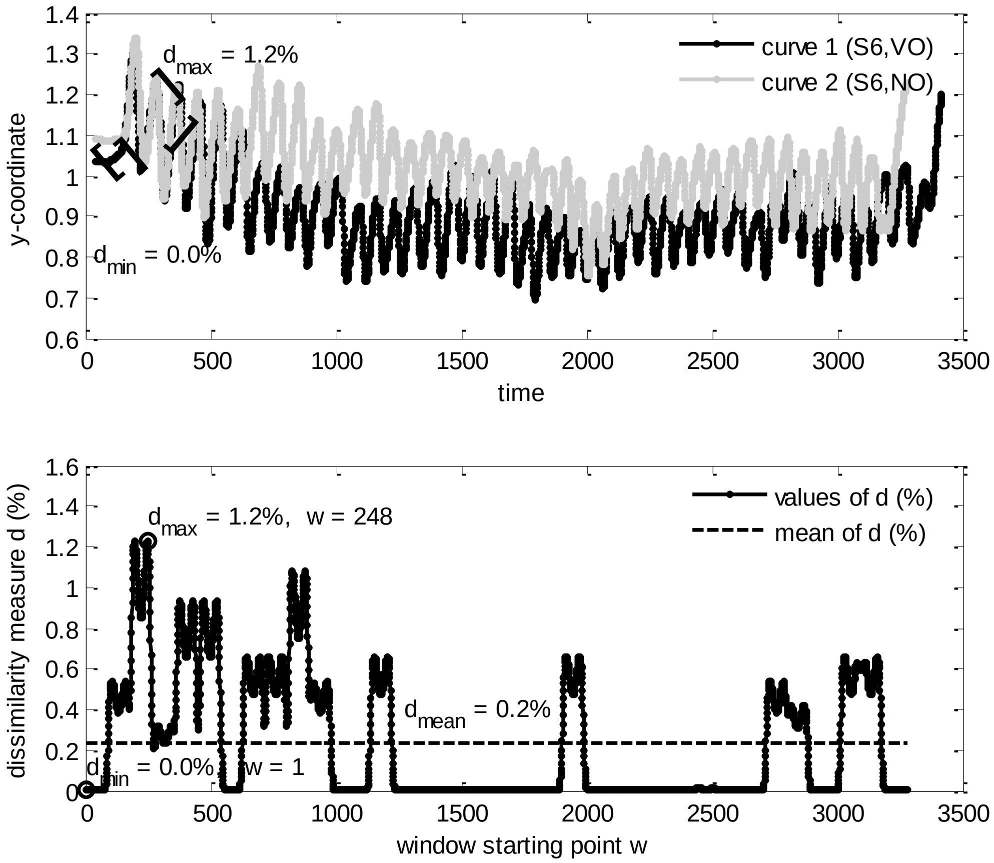

Figure 1. Wrist vertical position and dissimilarity measure over time for S6.

Table 1. Dissimilarity values between amateurs and professionals.

	Dissimilarity Values	
	Groups	
	Amateurs	Professionals
Paired Conditions		
1 - VONO	.470±.351	.118±.110
2 - VOBO	.487±.369	.177±.127
3 - VOAO	.434±.370	.116±.091
4 - AOBO	.248±.268	.134±.117
5 - BONO	.326±.291	.217±.189
6 - AONO	.197±.189	.128±.137

Note. The values are means ± standard deviations

The mixed ANOVA for Repeated Measures and Two Groups revealed that: (i) there was no interaction effect ($F_{(2.29,41.22)} = 3.15$, $p = .05$); (ii) there were significant differences between the dissimilarity of the paired conditions ($F_{(2.29, 41.22)} = 3.23$, $p = .04$); (iii) there were significant differences between the dissimilarity of the groups ($F_{(1,18)} = 6.20$, $p = .02$). The Bonferroni's post-hoc comparisons pointed to the existence of significant differences between the paired conditions 2 - VOBO and 4 - AOBO ($p < .01$). Figure 2 shows the profile plot with the estimated marginal means for each paired conditions and each group.

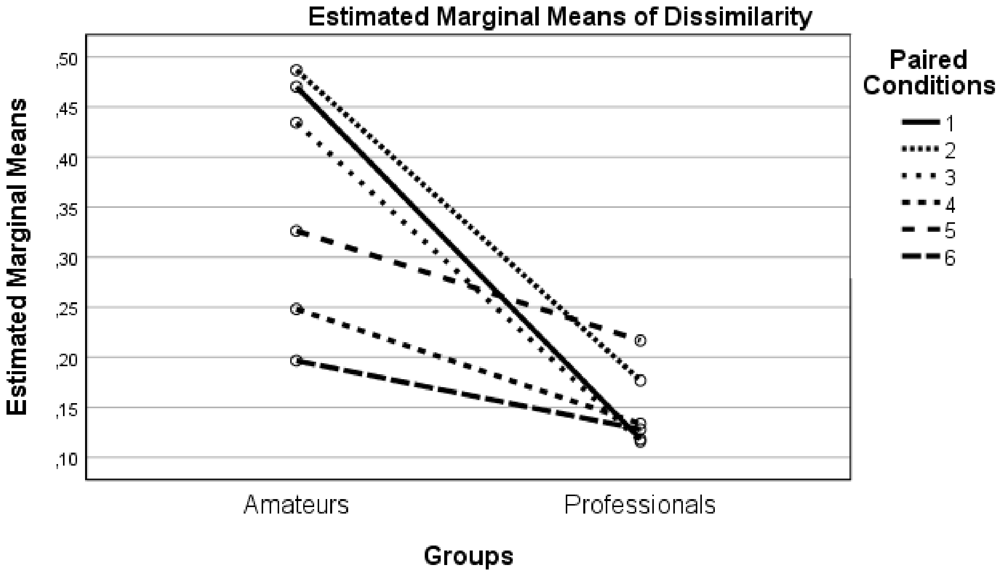

Figure 2. Professionals and amateurs dissimilarity mean values

As previously mentioned, some independent samples t-tests and paired samples t-tests were then performed to determine the specific origin of the observed differences.

Regarding the between groups comparison, dissimilarity in paired conditions including peripheral visual occlusion (VO) was significantly larger in amateurs when compared to professionals. More precisely, the mean dissimilarity between the peripheral vision occlusion (VO) and no occlusion (NO) conditions for amateurs was almost four times higher than for professionals (i.e., for VONO, mean = .470 for amateurs, mean = .118 for professionals, *p* = .01). Furthermore, the other pairs composed by peripheral vision occlusion (VO) with any other occlusion (BO and AO) guaranteed the existence of a higher, statistically significant, amateurs mean dissimilarity compared to professionals mean dissimilarity (i.e., for VOBO, mean = .487 for amateurs, mean = .177 for professionals, *p* = .03; for VOAO, mean = .434 for amateurs, mean = .116 for professionals, *p* = .02). Finally, the remaining pairs did not show significant differences in terms of mean dissimilarity between amateurs and professionals.

With respect to the within groups comparison, it was important to identify if auditory occlusion (AO) had an impact on the individuals' performance when combined with peripheral vision occlusion (VO). To do so, paired samples t-tests were used to assess eventual significant differences between VONO (peripheral vision occlusion and no occlusion) and BONO (both occlusions and no occlusion) mean dissimilarity in amateurs and in professionals. No significant differences were found, either in the amateur group (i.e., for VONO-BONO, mean = .144, *p* = .18) or in the professional group (i.e., for VONO-BONO, mean = .099, *p* = .11).

Discussion

Following Heinen and Vinken (2001) advice, we tried to quantify the impact of a perceptual source in the performance of basketball dribbling through the paradigm of occlusion. The adopted hypothesis was supported by two reasonably, theoretically supported assumptions: 1) wrist position in a static dribbling task is an indicator of performance (i.e., being the wrist on the end of the upper limb kinetic chain, unlike other more proximal joints, its stability is important for task performance) (Robalo et al., 2020); 2) professional players are better at dribbling than amateur players.

Basing the study on this premise we hope to contribute to the understanding on how skill level and specific perceptual source constraint might impair dribbling performance.

The perceptual sources that we chose to constraint were: 1) peripheral vision; 2) auditory. They were both analyzed separately and together. It seemed logical to choose these two sources because both are generally, occluded during a competitive situation. Whether it happens because the ball carrier directs its attention to the environmental aspects of the game (Maurer & Munzert, 2013), or because of the noise of the arena, the performer often finds himself in perceptual deprived setup.

The professional group had more experience than the amateur group, which meant that their perceptual attunement was naturally more optimized, since this is a process acquired and develop by training (Fajen et al., 2008). This process allows experienced individuals to thrive in perceptual deprived environments (Bennett et al., 1999; Stoffregen & Bardy, 2001) and that might be one reason why dissimilarity between trajectories in the no occlusion and peripheral vision occlusion conditions were almost four times greater in amateurs comparing to professionals (.470±.351 to .118±.110). The professionals somehow find strategies to have low levels of dissimilarity even with their peripheral vision occluded. This contradicts the findings of Heinen and Vinken (2001) and scepticism of Bennet and colleagues (1999) about the system's ability to fully replace vision function in sports performance. This study raises the hypothesis that the ability to fully replace a perceptual source occlusion might be task specific and dependent on the skill level of the performer.

Peripheral vision occlusion influences dribbling performance, when professionals were exposed to this condition they respond with a higher elbow lateral variability as well as a higher shoulder horizontal (i.e., anterior-posterior and lateral) variability when compared to amateurs (Robalo et al., 2020), with the current study we now know how much impact this type of occlusion has on dribbling performance itself.

Auditory occlusion did not show any influence on dribbling performance, when comparing amateurs and professionals (p =.37). An additional test was made using a paired samples t-test in order to assess if the addition of auditory occlusion to peripheral visual occlusion caused any additional significant differences on the results within both groups. It did not. Differences were not significant in both groups (i.e., amateurs – p =.18; professionals – p =.11). Auditory occlusion, for this task, using these variables to assess, is irrelevant for performance.

Conclusion

The impact of an occlusion of a perceptual source on the trajectory of the wrist, being a joint on the end of the kinetic chain, could signal its importance for dribbling motor control performance. This study showed how amateurs and professionals dribbling performance was impacted differently when peripheral vision occlusion was present. The dissimilarity of wrist vertical trajectories was almost four times greater in amateurs than professionals.

Assuming professionals' behaviour is an expression of a greater adaptive ability, amateurs should, eventually, be forwarded into learning situations where they are encouraged to develop the specific adaptations shown by professionals when dealing with perceptual deprivation in order to one day reach the stage where their performance is not impacted by peripheral vision occlusion.

Auditory occlusion shown no effects on performance even when it was combined with the peripheral vision occlusion, no additional effects were found.

General Discussion

The scarcity of scientific work on dribbling motor control, propelled us to try to help build a basis of knowledge for this matter. The scientific validation (or invalidation) of some current empirical knowledge used as common sense on basketball circles seemed somewhat of a necessity.

Regarding the basketball dribble as a skill, there are some technical aspects that, for experienced coaches, characterize skilled dribblers. The ability to free vision control off the ball while dribbling is one (Adelino, 1991; Ferreira, 2019), other, is the importance of lowering the height of dribble to, hypothetically, control it better due to a reduced ball time of flight (Adelino, 1991; Ferreira, 2019). Despite this knowledge being preached for decades, there is no scientific based literature to help understand which aspects effectively differentiate a skilled dribbler from an unskilled one.

Studying the dribble in a static task (i.e. no overall displacement of the individual) does not fully represent the nature of dribbling in a competitive situation but provides us the adequate setup to isolate variables to a point where we can quantify the impact of, for example, a specific perceptual source occlusion. The need to better our understanding on articular behavior during execution, depended on the ability to record joint position with no recording gaps which contributed to this task choice too. Although the task might not represent all the types of dribbles observed in a competitive match, it analyses a specific type of dribble that is, among others, tackled by empirical-based literature (Adelino, 1991; Ferreira, 2019). Before eventually, study the dribble in more dynamical or competitive situations, we thought that we should laid the theoretically basis on this specific task motor control by identifying what characterized a better adaptive behavior regarding a static dribbling task.

In our point of view basketball dribbling could not be lightly compared to any other sport skill regarding motor control. Although performance variables are task specific, there are some commons traits to variability/stability patterns observed throughout most of sports skills (Scholz & Schöner, 1999; Kelso & Engström, 2006) that could lead one to assume that studying the basketball dribble could be somewhat redundant. But what other sports skill consists on a constantly interceptive, perceptually intermittent execution? The unique features of this basketball skill made it impossible to find analogous studies.

Results made us hypothesize that perceptual attunement (Fajen, 2005) would be particularly important to performance, therefore not only motor execution would be a factor of success but also the ability to handle perceptual information (or lack thereof). Identifying how individuals with different experience levels handled peripheral vision and/or auditory occlusion was one of the main goals of this thesis.

To do so, we resorted to a plethora of mathematical methods so we could build a robust basis of knowledge on this subject. Non-linear, synergistic and dissimilarity assessment methods were used in order to fully understand the dynamical behavior of the variables chosen, avoiding "data normalization" (Buzzi et al., 2003) and focusing the work on how data pattern changes over time (Dingwell & Cusumano, 2000; Hausdorff et al., 1997). Strengthening the information on dribbling motor control paradigm meant, for us, identifying adaptive joint behavior and ultimately quantifying performance.

Variability

First, we begun analyzing joint position variability in both groups when exposed to each one of the conditions (i.e. peripheral vision occlusion, auditory occlusion, both occlusions, no occlusion). Within groups, amateurs reacted to peripheral vision occlusion (i.e. compared to the no occlusion condition) with a higher stability in the shoulder vertical movements suggesting that these individuals might be trying to stabilize their position as much as they could so they would not impair their dribbling performance, which was predictable since when learning to dribble, players are often asked to keep their eyes off the ball and to low their center of gravity (Adelino, 1991; Ferreira, 2019). Still for amateurs, under peripheral vision occlusion, lateral elbow movement was significantly more variable, a behavior that further on would be identified as an adaptive mechanism (i.e. professionals showed an even greater elbow lateral variability in the presence of peripheral vision occlusion indicating that is an underdeveloped adaptive response by the amateurs). Wrist stability was significantly higher for amateurs in the no occlusion condition compared to the other three conditions, indicating that perceptual disturbance could impair wrist position stability values in amateurs.

Professionals reacted to peripheral vision occlusion with a higher lateral shoulder movement, which represents torso movement and/or displacement of the overall torso location, an ability that was not shown by the amateurs. This higher shoulder lateral variability is an adaptive response to a perceptual occlusion and might be key to task completion in a visual constrained situation. The ability to displace the whole body or move the torso while dribbling represents the system ability to search solutions in order to sustain the proposed task.

Comparing both groups was crucial to understand the role of variability on dribble motor control, and once again, assuming that professionals are better at dribbling than amateurs, significant differences on joint behavior might represent adaptive mechanisms towards performance success. The most evident result was on how, through all conditions, wrist position stability was higher for professionals. Being the wrist the most distal joint assessed, and since is in the end part of the kinetic chain of dribbling, stability asserted itself as essential to successfully complete the task (Scholz & Schöner, 1999). Regarding the elbow, when in the presence of peripheral vision occlusion, anterior-posterior movement was more variable in amateurs than professionals, contrary to what was observed in lateral movements. For the same joint, variability/stability paradigm changed with axis that was being assessed. Shoulder horizontal movement (i.e. anterior-posterior and lateral) was significantly more variable in professionals than amateurs.

Auditory occlusion by itself, did not influence joint variability overall. Although when combined with peripheral vision differences were observed in some joints behavior (e.g. lateral elbow movement), the origin of those differences, as other results indicate, was probably attributed just to the lack of visual information. Although auditory occlusion, probably did not influence joint variability in both groups, the magnitude of the possible cumulative effects of the auditory occlusion with peripheral vision occlusion on performance was yet to be determined. Impairing a perceptual source could promote the substitution of the lacking information by the other available sources perceptual information through a better perceptual attunement (Fajen, 2005). This hypothesis remained, thus far, unanswered. There was still a chance that auditory occlusion might influence dribbling motor control when paired with peripheral vision occlusion, in a way that its contributions in a visual deprived setup compensated the lack of visual information.

It is noteworthy that, for both groups, the movement adjustments under perceptual occlusions were performed by proximal joints, the shoulder and the elbow, whereas for the wrist (with more degrees of freedom) no differences were detected. This may suggest that the shoulder and the elbow adjust to each other (even in different plans of movement) to stabilize the movement of the wrist, this presupposition brought us the second study problem.

Synergies

In the second study, we tried to understand if the elbow and shoulder angular movement did co-vary between them in order to stabilize wrist vertical position. And if this co-variation was constant throughout the whole dribbling cycle. Synergies were evaluated using an UCM method, and values were recorded at the wrist highest and lowest points of each cycle. The highest point corresponded to the specific time where the hand deaccelerates ball vertical movement to velocity zero and the lowest point corresponded, approximately, to the moment the ball hits the floor (i.e. there is no contact between hand and ball).

Results showed that both, amateur and professional, groups had synergistic behaviors between shoulder and elbow at dribbling cycle wrist peak height. Which confirmed the assumption raised at the end of the first study. After all, shoulder and elbow compensated each other in order to stabilize wrist position, and were potential intrinsic mechanisms to adapt to constraints. At the lowest point of the dribbling cycle synergistic behavior was not observed, whether it was because of lack of need to do it due to task specificity or because of the lack of perceptual information (i.e. because there is no perceptual information available at this point of the cycle) is still yet to be determined.

These results are in compliance with theoretical assumption that proximal joints, such as shoulder and elbow in this specific task, show higher levels of angular variability in order to provide the systems the needed flexibility to adapt to constraints. The synergy between these two joints is crucial for stabilizing wrist vertical position, variable that, for this task, emerged as a performance factor.

Dissimilarity

In the previous articles wrist vertical position, asserted itself as performance indicator. The arguments to support that assumption are: 1) wrist position variability was lower when amateurs had no perceptual source occlusion compared to the occluded conditions; 2) when comparing both groups, wrist position stability was higher for professionals throughout all conditions; 3) wrist vertical position was stabilized by a shoulder/elbow synergy.

Trajectories assessment allowed to continuously assess wrist vertical position along the execution of 42 dribbles, designing the spatial behavior of an end-effector variable. Dissimilarity, calculated by a Procrustes analysis, was used to precisely quantify how much different trajectories were, making it possible to identify how impactful was the occlusion of a specific perceptual occlusion on performance. Comparing both groups mean values, amateur had dissimilarity values almost four times higher than professionals when exposed to peripheral vision occlusion, which meant that the impact of peripheral vision occlusion in dribbling performance is four times greater in amateurs than professionals. For auditory occlusion alone, no differences were found. In order to find if auditory occlusion had any cumulative effect on performance when paired with peripheral vision, mean dissimilarity values between two paired conditions: 1) peripheral vision occlusion and no occlusion; 2) both occlusions and no occlusion; were assessed. No significant differences were found.

Overall conclusions

Differences in adaptive mechanisms between amateurs and professionals could help us understand how does joint behavior evolves with the increase of experience. Studies that use the perceptual occlusion paradigm allow us to identify the importance of a specific perceptual source for motor control. The adaptive behavior registered in the presence of perceptual challenges that are present in the competitive situation enabled the study to increase its representativeness. For basketball dribbling, peripheral vision occlusion promotes adaptations towards a more mature joint behavior observed in professional players. The increased values of shoulder horizontal movement (i.e. anterior-posterior and lateral) and elbow lateral movement variability constituted performance factors that confer the system its ability to be flexible and adapt to constraints. Wrist vertical stability, asserted itself as a performance indicator for this specific task, allowing us to assess that for amateurs, performance is affected almost four times more than professionals.

Practical applications

The fact that peripheral vision occlusion guides the individual towards a more mature strategy to handle dribbling motor control, its use in a training or learning context seems extremely useful. Designing training situations that promote the deviation of visual attentional focus to environmental issues as well as situations with overall torso displacement (i.e. stimulating shoulder horizontal displacement) or situation with variating lateral distance of ball in relation to the body (i.e. stimulating elbow lateral movement) might be key to develop joint behaviors observed in professionals. Athletes have to be guided to find, through practical situations, their own perceptual and motor strategies to handle constraints.

Main limitations

Conceptually, for the chosen task, the limitations were not significant. For a static dribbling task, the motion capture of the three main upper limb joints (i.e. shoulder, elbow and wrist) through reflective markers with six cameras and a 3D software to treat data was adequate. The main limitation was, for now, not being able to increase task representativeness with a more dynamical situation, or even with opposition. For this to be possible the facilities where the experiment was recorded had to be significantly bigger and the number of cameras used had to be higher. In order to register markers at all times at least two cameras have to caption its motion, with more cameras the occlusion of marker (e.g. because a defender is covering the ball carrier camera angle) would be more easily compensated by extra camera angles. The inability to register ball movement precisely with 6 cameras made it impossible to include ball variables (i.e. namely hand-ball coupling variables) into these studies.

Issues for further research

Connecting hand-ball coupling variables with articular variables would allow to study dribbling motor control in more representative environments. Studying basketball dribbling in more dynamical situations, eventually with opposition would be an ideal scenario. This kind of experimental design would present serious challenges due to motion capture conditions, nonetheless the type of information that could come out of such studies would not be nothing short of remarkable. Using dissimilarity to assess performance evolution would be something particularly useful for beginners.

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