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Full Length Article

Coordination and control of posture and ball release in basketball free-throw shooting

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ABSTRACT

The objective of this study was to investigate the coordination of a whole-body task (basketball free-throw) in which success in performance outcome can be achieved through a manifold of combinations of postural and movement trajectory configurations. Participants were healthy men (19–24 years) with a range of skill levels that were tested for the accuracy of 50 basketball free-throws with both their dominant and non-dominant hand. The trial-to-trial variance in release parameters as well as postural stability of the shooter and synchronization of postural movement and ball release were strong predictors of performance, with non-elite shooters having a higher mean and variability of center-of-mass (COM) speed at the time of ball release. The synchronization between the time of peak COM and the time of ball release increased as a function of skill level and hand dominance, with the better performers releasing the ball more closely to the time of COM peak height. These findings reveal how, in addition to successfully controlling the trial-to-trial variability along the solution manifold of release parameters, the relative importance of the coordination of postural control and ball release properties on shooting success changes as a function of skill level.

1. Introduction

Bernstein (1967) put forward that the acquisition of a motor skill is essentially about the mastery of redundant degrees of freedom (DOF). There are DOF at all levels of analysis of the human action system (Mitra, Amazeen, & Turvey, 1998; Turvey, 1990). Nevertheless, the central point of analysis in motor skill acquisition, outside of movement outcome, has been the DOF in joint space.

The mastery of these redundant DOF can be realized through practice. But, and in spite of, the accepted central role of practice in motor skill acquisition (Newell & Rosenbloom, 1981; Newell, 1991, 1996), there are no influential extant theories of practice. Extreme positions on the role of practice – environmentalism (Ericsson, Krampe, & Tesch-Römer, 1993) on one side and hereditarianism (Thorndike, 1908) on the other – have persisted, although, more recent positions have advocated an interactive role for both nature and nurture. Nevertheless, despite the fact that there seems to be an agreement that practice is a requirement for successful performance (Ackerman, 2013), the lack of a relevant theory in regard to the particulars of practice for motor skill acquisition and even more so the shortage of empirical evidence for the principled roles of practice, makes it difficult to go beyond that statement.

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The challenge is to understand how through practice the many DOF are harnessed qualitatively and quantitatively into patterns of movement coordination and control in the pursuit of realizing a task goal (Gel'fand & Tsetlin, 1962). The predominant approach across a long history of theoretical viewpoints (reinforcement, closed-loop, motor programs, schema), has been to investigate motor learning in scaling tasks, where the learner can already produce a task relevant coordination mode that needs scaling in space, time, force and so on to meet the environmental and task demands (Newell, 1985). Likewise, many experimental paradigms have been limited to single-effector movements, reducing the joint space DOF to 1 functional dimension. The shortcomings of this approach lead to a restricted view on the changes in motor control as a function of practice. The net result is that there are relatively few studies in adults on the foundational stage of the coordination of multiple DOF in motor learning, though there are exceptions (see Arutyunyan, Gurfinkel, & Mirskii, 1969; McDonald, Van Emmerik, & Newell, 1989; Vereijken, van Emmerik, Whiting, & Newell, 1992).

The current study investigates the biomechanical variables that contribute to shot success in basketball free-throw shooting for performers at different skill levels. Thus, here we are not investigating the effect of practice directly, but rather we examine in an individual participant design the differences in movement system organization as a function of skill level in dominant and non-dominant hand basketball shooting. Understanding the biomechanical variables that relate to performance outcome in a whole-body task, that requires the coordination and control of multiple degrees of freedom, will contribute to decomposing the critical components of basketball free-throw shooting. Not only does this increase the ability to understand the transitions of coordination modes as a function of skill level, the information arising about the critical variables can be used to facilitate the acquisition of the free-throw skill through a change agent (coach) as well as objectively select the most skilled performers. Thus, gaining an understanding about the relative importance of individual components of the movement execution could be beneficial in improving skill for non-elite players and guiding coaches to target specific variables that are crucial in the acquisition of the free-throw shot skill.

The experiment was set up to directly investigate a system's approach to motor skill acquisition (Gel'fand & Tsetlin, 1962) from the anticipation that the relative contribution of both ball release kinematics (Robins, Wheat, Irwin, & Bartlett, 2006), as well as postural biomechanics (Hudson, 1985), to overall shot success changes as a function of free-throw skill level. Firstly, we hypothesized that because of the degenerate nature of the task, between-subject differences in task performance will not necessarily be expressed solely through differences in the ball release parameters. This is because an increase of coordination and/or co-variation between the release parameters could be predictive of performance as examined by the uncontrolled manifold (UCM) framework (Scholz & Schöner, 1999). Given that performance in the task is governed by a distinct function (see Section 2), it could be that skilled performers control the movement along the subspace that consists of the set of parameters that lead to zero error, instead of controlling the contributing variables individually and independently. Secondly, since learners of basketball shooting produce different postural coordination modes in shot production as a function of skill level (Hudson, 1985), this experiment will investigate the role of increased postural support as a moderator for successful task performance. It was hypothesized that low-level shooters will have higher postural instability and variability, together with higher variability orthogonal to the task subspace, whereas elite shooters will reduce their postural instability as well as their task-relevant variability. Thirdly, we investigated the hypothesis that the dynamic expressions of postural control and release parameters become increasingly linked (coupled) as a function of skill level reflecting the changing global organization (Gel'fand & Tsetlin, 1962; Mitra et al., 1998) of what have been typically seen as independent properties of posture and movement in this whole-body task of basketball free-throw shooting.

2. Methods

2.1. Participants

A total of 25 male college students (age 19–24 years) were recruited from volunteers at the University of Georgia campus. To attract a broad range of potential skill levels, no prior competitive playing experience with basketball was required. Individuals with (minor) injuries were excluded from participation. Informed consent was obtained from all participants, consistent with the approval of the University of Georgia Institutional Review Board, and all were assigned to the same experimental task.

2.2. Materials

All data collection took part at the Biomechanics Laboratory at the University of Georgia. The free-throw shot was recorded at 120 Hz through 8 VICON (Vicon Industries Ltd., Hampshire, United Kingdom) Bonita Optical motion capture cameras and reflective markers and analyzed through the VICON Nexus 2.0 software. The body of the participant was equipped with 30 markers according to the VICON Plug-in-Gait Marker Placement and the basketballs with 5 additional 12.5 mm markers each, in line with the marker placements of Mullineaux and Uhl (2010). The smaller marker size was chosen to minimize interference in the shooting task. Markers were attached using industrial strength hook- and loop-fasteners, allowing for quick reattachment during the few trials a marker got stuck behind the net. All basketballs were Wilson NCAA Replica Game Basketballs. The basket was placed at the regulation 15 ft (457 cm) from the free-throw line and at a height 10 ft (305 cm) above the floor.