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Judging complex movement performances for excellence: A principal components analysis-based technique applied to competitive diving

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ABSTRACT

Athletes rely on subjective assessment of complex movements from coaches and judges to improve their motor skills. In some sports, such as diving, snowboard half pipe, gymnastics, and figure skating, subjective scoring forms the basis for competition. It is currently unclear whether this scoring process can be mathematically modeled; doing so could provide insight into what motor skill is. Principal components analysis has been proposed as a motion analysis method for identifying fundamental units of coordination. We used PCA to analyze movement quality of dives taken from USA Diving's 2009 World Team Selection Camp, first identifying eigenpostures associated with dives, and then using the eigenpostures and their temporal weighting coefficients, as well as elements commonly assumed to affect scoring – gross body path, splash area, and board tip motion – to identify eigendives. Within this eigendive space we predicted actual judges' scores using linear regression. This technique rated dives with accuracy comparable to the human judges. The temporal weighting of the eigenpostures, body center path, splash area, and board tip motion affected the score, but not the eigenpostures themselves. These results illustrate that (1) subjective scoring in a competitive diving event can be mathematically modeled; (2) the elements commonly assumed to affect dive scoring actually do affect scoring (3) skill in elite diving is more associated with the gross body path and the effect of

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the movement on the board and water than the units of coordination that PCA extracts, which might reflect the high level of technique these divers had achieved. We also illustrate how eigendives can be used to produce dive animations that an observer can distort continuously from poor to excellent, which is a novel approach to performance visualization.

1. Introduction

Athletes in most sports must learn to perform complex multi-joint movements with great skill. They typically receive feedback about the quality of their movements from coaches, or in some sports, such as diving, gymnastics, snowboard half-pipe, and figure skating, judges. The availability of the feedback depends on the availability of the evaluator, and the quality of the feedback depends on the level of expertise of the evaluator. It is often uncertain whether an explanation of a score provided by an evaluator actually concurs with the quantitative elements of the movement – do the features evaluators verbally single out as influencing their judgments actually determine skill?

The goal of this work was to develop a mathematical technique to judge the quality of a complex sporting movement and to apply the technique to data from a competitive diving event to gain insight into motor skill. Quantifying athletic performance with sensors to gain insight into judging has been proposed previously (Gordon, 1995; Harding, Small, & James, 2007; Hiley & Yeadon, 2012; Shin & Ozawa, 2008; Siegel, 2009). For example, studies of half-pipe snowboard competition found that total air time measured using video capture or worn accelerometers (Harding et al., 2007) and total angular rotation measured with worn rate gyroscopes (Harding, Mackintosh, Martin, Hahn, & James, 2008) each strongly correlated with the overall competition score, with variance accounted for about 30%. These researchers held their own competition (Harding, Toohey et al., 2008), and studied data from previous competitions (Harding & James, 2010) and found they could explain about 70–90% of judges' scores using a regression equation incorporating both of these variables.

The finding that two summary parameters of the physics of the motion captured much of the variance of an elite performance sport raises the question of how much the details of the multijoint coordination pattern matter in skill perception. It may be that observers and judges mostly observe the summary effects caused by the intricate coordination of the body and its effect on the environment, rather than the coordination pattern itself, at least for elite athletes.

Principal components analysis has been increasingly applied in motion analysis studies to extract fundamental patterns of coordination of complex movement (see tutorial Daffertshofer, Lamoth, Meijer, & Beek, 2004). In a similar paper, (Troje, 2002) used principal component analysis to automatically identify eigenpostures associated with stylistic differences of walking movements, between females and males, old and young, sad and happy, and nervous or relaxed walkers. Others have recently used this method to analyze sports technique, for example in racewalking to identify technical differences between higher and lower skilled athletes (Donà, Preatoni, Cobelli, Rodano, & Harrison, 2009) and in ski racing to objectively analyze human movement in a way similar to how human coaches would describe the movement (Federolf, Reid, Gilgien, Haugen, & Smith, 2012). PCA-based or similar techniques have also been hypothesized to allow the identification of the "fundamental motor modules", "functional units of coordination", "synergies", or "coordinative structures" through which the motor system constructs gait and other movements (e.g., Daffertshofer et al., 2004; Moreno et al., 2013; Torres-Oviedo & Ting, 2010).

Here, we chose to use the PCA-based method because of its putative capability to extract basic patterns of joint coordination from large motion capture data sets. If joint coordination matters for elite skill assessment, such PCA-based techniques could provide a way to automatically isolate the joint coordination features that influence judging. Another feature of the method used by Troje (2002) that attracted us to study it here was that it allowed the synthesis of point-marker animations of people