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Skill level constrains the coordination of posture and upper-limb movement in a pistol-aiming task

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ABSTRACT

The purpose of the experiment was to investigate whether skill level differentially organizes the coordination of the postural system and upper limb kinematics in a pistol-aiming task. Participants aimed an air-pistol at a target center in 30 s trials as accurately as possible while standing on a force platform with shooting arm joint kinematics recorded. The novice group had greater motion of the pistol end point, arm joints and the center of pressure than the skilled group. Principal components analysis (PCA) showed that the skilled group required 2 components as opposed to the 3 components of the novice group to accommodate the variance. Coherence analysis in the 0–1 Hz bandwidth revealed that the coupling between posture and upper-limb movement was stronger in the skilled than the novice group. The findings are consistent with the view that skill acquisition reduces the kinematic variables into a lower dimensional functional unit that in pistol-aiming is defined over the collective posture and upper-limb system.

1. Introduction

A goal-directed aiming task such as pistol-shooting involves multi-joint arm motions and minimal fluctuations of movement amplitude at its end point (e.g., gun barrel) to achieve a high degree of performance accuracy. It has been shown that there are a number of processes contributing to the realization of successful performance in this task including psychological (e.g., intention and stress; Landers, Qi, & Courtet, 1985; Loze, Collins, & Holmes, 2001) and neurophysiological (e.g., cardiovascular adaptation and physiological tremor; Fenici, Ruggieri, Brisinda, & Fenici, 1999; Kelleran, Morrison, & Russell, 2016; Lakie, Villagra, Bowman, & Wilby, 1995; Tang, Zhang, Huang, Young, & Hwang, 2008). Here we focus on how the skill level influences the coordination and control of upper-limb and posture motion in a pistol-aiming task.

1.1. Pistol aiming studies

To achieve accuracy in pistol-aiming fundamentally requires the shooter to align the gun barrel with the target. This means that the redundant kinematic arm joint motions (Bernstein, 1967) need to be effectively constrained and coordinated to manage the orientation of the gun with the target. This was initially investigated in the classic studies of Arutyunyan, Gurfinkel, and Mirskii (1968, 1969) that compared pistol shooting in experienced and inexperienced marksmen. They showed that the experienced group had a smaller dispersion of the gun motion compared to the inexperienced group. Furthermore, the reduced gun motion of the

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experienced group was related to the released joint motions of the arm and the presence of compensatory arm-motion synergies. In contrast, the inexperienced group controlled the gun with tightly fixed kinematic linkages of the arm joints and was, in effect, controlling the act of pistol-shooting from the shoulder joint.

1.2. Postural control in aiming tasks

Postural control is a critical factor for the control of arm motion in accurate pistol aiming. Successful performance of aiming and pointing tasks requires the integration of posture and limb control and the coordination of multiple degrees of freedom (DOF) (Bernstein, 1967). In shooting tasks, a number of studies have shown that stable postural balance control is significantly related to high-level performance. For example, in rifle (Era, Konttinen, Mehto, Saarela, & Lyytinen, 1996) and sharp (Konttinen, Lyytinen, & Era, 1999) shooting studies experienced shooters showed a reduced amount of motion of the center of pressure (COP) compared to inexperienced shooters. Mononen, Konttinen, Viitasalo, and Era (2007) have suggested that an unstable postural balance (e.g., larger COP motion) influences the greater motion of the gun barrel and results in a poor performance score.

The relation between postural COP control and the gun barrel movement or shooting score has been analyzed by the respective linear motion parameters (e.g., standard deviation, velocity, and root mean square, etc.) of these variables. How the upper-limb kinematics are co-related or co-varied with postural control during a pistol-shooting task has not been directly studied. The analysis of coordination and control between postural balance and arm joint motion as a function of skill level was the central issue of the present study. In particular, we sought to understand how the COP differentially supports multi-joint arm movements for minimizing fluctuations of the end point (e.g., gun barrel) between novice and skilled shooting groups.

1.3. Hypotheses

The purpose of the experiment was to investigate whether there are different: 1) organizational structures in the upper limb kinematics and postural control system between novice and skilled groups during a pistol aiming task; and 2) coordination patterns between the postural control and arm joint kinematics for the two skill level groups. The hypotheses examined in the study were as follows. There would be a different organizational structure of posture-arm motion between two groups with the skilled group showing: (1) a smaller number of dynamical DOF as indicated by the reduced estimate of independent components in the principal components analysis (PCA), and (2) a tighter coupling between the postural control and upper limb kinematics.

The PCA was applied to examine the qualitative properties of movement organization. PCA allows one to compress the original pistol, arm joint and postural COP motions in a higher dimensional space into a lower dimension where it is a functional control space with independent components produced by a weighted combination of the variables (Daffertshofer, Lamoth, Meiher, & Beek, 2004; Ko & Newell, 2015). The PCA provides a method to estimate the number of dynamical DOF in the lower dimensional control space (Ko, Challis, & Newell, 2013; Li, 2006; Newell & Vaillancourt, 2001).

2. Methods

2.1. Participants

Sixteen healthy male volunteers participated in the study. The participants were assigned to two groups based on their experience of air-pistol shooting. A skilled group consisted of 8 well-trained air-pistol shooting players who were currently participating in university level shooting competitions. The skilled group had at least 6 years (6–8 years) of air-pistol shooting training and their mean age was 22.5 years (range: 21–24 yr, SD = 1.2). A novice group consisted of 8 sex- and age-matched university students with no prior air-pistol or gun shooting experience. The mean age of the novice group was 22.2 years (range: 21–24 yr, SD = 1.0). The participants were all right-handed and indicated that they were free of any neurological disease or musculoskeletal dysfunction that might negatively influence the air-pistol shooting performance. The study was approved by the Chonbuk National University Review Board and all participants gave informed written consent prior to the testing.

2.2. Apparatus

For the pistol-aiming task, an air pistol (weight 1.5 kg, 4.5 mm caliber) that is used for real 10 m air pistol competition was provided for the participants. Prior to testing, 4 reflective markers were attached on the barrel of the pistol, wrist (ulnar styloid), elbow (radius head), and shoulder (acromion process), respectively (Fig. 1). The Optotrak Certus (Northern Digital Inc., Waterloo, Canada) with 3 cameras, uniformly placed on the floor, captured these markers in the anterior-posterior (AP), medial-lateral (ML), and vertical (VER) directions. A Bertec force platform (Bertec Corp., FP4060-08, Columbus, OH, USA) placed on an even floor was used to measure the total body COP both in the AP (COP_{AP}) and ML (COP_{ML}) directions. The motion capture system and the force platform were synchronized for data collection (sampled at 100 Hz). The raw data were filtered after collection by a low-pass forth-order Butterworth filter with cut-off frequency at 5 Hz for further analyses.

2.3. Procedures

Participants were required to aim the air-pistol at the origin of target as accurately as possible without any motion. To perform the