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Individual differences in the biomechanical effect of loudness and tempo on upper-limb movements during repetitive piano keystrokes

Shinichi Furuya [a,b,*], Tomoko Aoki [c], Hidehiro Nakahara [d], Hiroshi Kinoshita [e]

[a] Japan Society for the Promotion of Science (JSPS), Chiyoda-ku, Tokyo 102-8472, Japan
[b] School of Science and Technology, Kwansei Gakuin University, 2-1, Gakuen, Sanda, Hyogo 669-1337, Japan
[c] Faculty of Environmental and Symbiotic Sciences, Prefectural University of Kumamoto, 3-1-100 Tsukide, Kumamoto City, Kumamoto 862-8502, Japan
[d] Morinomiya University of Medical Sciences, 1-26-16, Nankokita, Suminoe, Osaka 559-8611, Japan
[e] Graduate School of Medicine, Osaka University, 1-17, Machikaneyama, Toyonaka, Osaka 560-0043, Japan

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ABSTRACT

The present study addressed the effect of loudness and tempo on kinematics and muscular activities of the upper extremity during repetitive piano keystrokes. Eighteen pianists with professional music education struck two keys simultaneously and repetitively with a combination of four loudness levels and four tempi. The results demonstrated a significant interaction effect of loudness and tempo on peak angular velocity for the shoulder, elbow, wrist and finger joints, mean muscular activity for the corresponding flexors and extensors, and their co-activation level. The interaction effect indicated greater increases with tempo when eliciting louder tones for all joints and muscles except for the elbow velocity showing a greater decrease with tempo. Multiple-regression analysis and *K*-means clustering further revealed that 18 pianists were categorized into three clusters with different interaction effects on joint kinematics. These clusters were characterized by either an elbow-velocity decrease and a finger-velocity increase, a finger-velocity decrease with increases in shoulder and wrist velocities, or a large elbow-velocity decrease with a shoulder-velocity increase when increasing both loudness and tempo. Furthermore, the muscular load considerably differed across the clusters. These findings provide information to determine muscles with the

* Corresponding author. Address: Research Center for Human Media, Kwansei Gakuin University, 2-1, Gakuen, Sanda, Hyogo 669-1337, Japan. Tel./fax: +81 79 565 7861.
E-mail addresses: auditory.motor@gmail.com, sfuruya@umn.edu (S. Furuya).

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greatest potential risk of playing-related disorders based on movement characteristics of individual pianists.

1. Introduction

Playing-related musculoskeletal disorders (PRMD's) have long been prevalent among pianists. Survey studies have reported that more than 60% of piano players and teachers have suffered from this occupational disorder ranging from acute pain to more serious problems, such as tendonitis, carpal tunnel syndrome, and focal dystonia (Bragge, Bialocerkowski, & McMeeken, 2006; Bruno, Lorusso, & L'Abbate, 2008; Furuya, Nakahara, Aoki, & Kinoshita, 2006; Jabusch, Vauth, & Altenmüller, 2004). Several studies also have attempted to qualitatively determine their risk factors, which included age, sex, practice duration, and anthropometric features of the hand (De Smet, Ghyselen, & Lysens, 1998; Furuya et al., 2006; Farias et al., 2002; Revak, 1989). In contrast, biomechanical factors that influence the physiological load at the upper-extremity muscles during piano playing have been not fully addressed, which has limited prevention, diagnosis, and treatment of PRMD's.

Loudness and tempo are fundamental musical variables that crucially influence the muscular load on the upper extremity during piano playing. Our previous study examined the effect of the loudness of a tone on the force applied to the fingertip during the keystroke (Kinoshita, Furuya, Aoki, & Altenmüller, 2007). The results demonstrated an exponential increase in the key-force with loudness. More recently, a series of our biomechanical studies found an increase in the magnitude of agonist–antagonist muscular co-activation, muscular torque, and kinetic energy at the upper extremity in proportion to loudness (Furuya & Kinoshita, 2007, 2008a, 2008b; Furuya, Osu, & Kinoshita, 2009; Furuya, Altenmüller, Katayose, & Kinoshita, 2010). In addition, the increases in co-activation and muscular torque with loudness were less pronounced for the expert pianists as compared to the novice piano players, which highlighted expertise-dependent differences in the muscular load during piano keystroke.

One limitation of these previous studies on the biomechanics of piano keystroke is that neither the effect of tempo nor the interaction of tempo and loudness on the kinematics and muscular activities of the upper extremity was investigated, because they only focused on a discrete piano keystroke. The information on the interaction of tempo and loudness is particularly important for determining muscles with the greatest potential risks of PRMD's during piano playing, since the muscular load should drastically increase when striking both stronger and faster (i.e., increasing both loudness and tempo). Another limitation is that none of the previous studies probed into individual differences in physiological load at the upper-extremity muscles. Due to the redundant number of joints and muscles, our motor system is capable of accomplishing a particular task goal with different movement organizations. It is thus reasonable to assume that the muscular load during piano playing would differ across pianists. To characterize it through examining a large number of players is indispensable because clinical and epidemiologic studies reported that the body portion with symptoms of PRMD's differed cosiderably across pianists (Bragge et al., 2006; Bruno, Lorusso, & L'Abbate, 2008; Furuya et al., 2006).

The primary purpose of the present study is to assess the biomechanical effect of loudness and tempo on repetitive piano key-striking movements. Our specific focus is on the interaction of these variables on movement kinematics and muscular activities. We postulate that changes in joint velocity and muscular activities in relation to loudness differ depending on tempo. The secondary purpose of the study is to evaluate the relationships between individual differences in the interaction effect on joint kinematics across pianists and the muscular load on the upper extremity. To this aim, we collected data from 18 pianists. We hypothesized that there should be a small number of representative kinematic strategies to strike stronger and faster; we also hypothesized that the muscular load should differ across these strategies. We tested them quantitatively using multiple-regression analysis and clustering analysis.