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Influence of aging on bimanual coordination control

Chueh-Ho Lin [a,b], Li-Wei Chou [a], Shun-Hwa Wei [a], Fu-Kong Lieu [c], Shang-Lin Chiang [d], Wen-Hsu Sung [a,*]

[a] Department of Physical Therapy and Assistive Technology, National Yang-Ming University, Taipei, Taiwan, ROC
[b] Department of Physical Therapy, Hung-Kung University, Taichung, Taiwan, ROC
[c] Cheng Hsin General Hospital, Taipei, Taiwan, ROC
[d] Tri-Service General Hospital, Taipei, Taiwan, ROC

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ABSTRACT

Degeneration in the neuromuscular system due to aging can affect daily activities that need to be controlled by bimanual coordination with both hands. However, little is known about the influence of aging on grip strength and bimanual coordination control between hands. The purpose of this study was to investigate the influence of aging on the maximum grip force output and capacity of coordination control of two hands. Ten healthy elderly and 21 young adults were recruited and asked to execute maximum grip force tests and bimanual coordination control tasks with reciprocal grasping, holding, and releasing of a dynamometer with both hands at three target force levels (10, 20 and 40% maximal voluntary contraction, MVC). Compared with the young group, the maximum grip force of the hands of the elderly group was significantly lower by 77.5% ($p < 0.05$) and 71.1% ($p < 0.05$) in the dominant and non-dominant hands, respectively. The elderly adults also displayed a significantly longer alternating time control in the dominant to non-dominant and non-dominant to dominant hands at the 20% MVC target force level ($p < 0.05$). Aging reduces the maximum hand grip force output and the performance of bimanual coordination control of two hands, which may lead to difficulty with the execution of daily activities requiring both hands.

1. Introduction

Aging causes a gradual degeneration of the neuromuscular system and cutaneous sensation (Bowden and McNulty, 2013; Naik et al., 2011; Roos et al., 1997; Tucker et al., 2008). These physiologic changes affect the functional performance of the hands of the elderly population (Bowden and McNulty, 2013; Desrosiers et al., 1999; Seidler et al., 2002), such as causing increases in the time spent in task execution, unstable grip strength (Cole, 1991; Galganski et al., 1993; Seidler-Dobrin et al., 1998) and a decline in the regulating and controlling capacity with fine motor control (Seidler et al., 2002). Because of the changes in physiology and function, elderly adults are unable to generate appropriate responses for the execution strategies of environmental or object manipulation involving coordination control among limbs (Tucker et al., 2008). Elderly adults are therefore unable to complete most daily activities that involve complex bilateral hand coordination and grasping with two hands (Kilbreath and Heard, 2005). The proportion of affected daily activities reportedly varies between 13% and 35% in the elderly population (Schultz, 1992). Therefore, the capacity for coordination control by grasping with two hands is very important for the elderly population for participation in daily activities and is related to independent living ability.

The clinical methods for evaluating bilateral hand coordination usually include the Minnesota Rate of Manipulation Test and Purdue Pegboard Manual Test. These tests are applied to determine the alternating time, measure the movement time and calculate the number of executions for completing tasks using two hands simultaneously (Aaron and Jansen, 2003; Clopton et al., 1984; Tiffin and Asher, 1948; Yancosek and Howell, 2009). However, such methods can measure the dexterity of hand function, but they cannot directly determine the quality of coordination control by grip force between two hands when executing these tasks with two hands simultaneously. Fortunately, evaluation tools, in combination with biosensors developed in recent years, can be effectively used to quantitatively evaluate and analyze the kinematics parameters related to the coordination control among limbs, such as measuring angle positions among joints, movement speed (Burgess-Limerick et al., 1993) and tracks and routes (Cattaert et al., 1999), which facilitates the understanding the operational state of the neuromuscular system. However, the kinematics changes measured by these tools cannot effectively evaluate the capacity and quality of coordination control via the grip force between two hands or determine the influence of different grip forces on bimanual coordination control. The operational definition of bimanual coordination control is the bilateral movements of daily activities executed with temporal, spatial, force or kinematics parameter symmetry or coupling between two hands,

* Corresponding author at: Department of Physical Therapy and Assistive Technology, National Yang-Ming University, No.155, Sec. 2, Linong Street, Taipei 112, Taiwan, ROC. Tel.: +886 2 28267910; fax: +886 2 28270140.
E-mail addresses: whsung@ym.edu.tw, wenhsusung@gmail.com (W.-H. Sung).

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such as holding a bottle and unscrewing the lid simultaneously (Krishnan and Jaric, 2010; Swinnen and Wenderoth, 2004). If the time spent in executing the coordination control by two hands and the change in grip force can be measured, the influence of aging on bimanual coordination control with grip force can be determined precisely and directly, which has been rarely discussed or determined in recent research, such as in a study by Mose and his colleagues, who designed a task to confirm the influence of aging on the interaction between bilateral hemispheres (Moes et al., 1995). In that task, the subject was required to turn a knob with two hands and operate two horizontal and vertical verniers at the mapping interfaces of a computer. The goal of the task was to complete a movement simultaneously with two hands. The performances between two hands affected one another, thus facilitating an understanding of the influence of changes in the corpus callosum on bimanual coordination control (Moes et al., 1995). This test has also been applied to patients with complete agenesis of the corpus callosum to determine the change in the integrating capacity of the bilateral hemispheres (Mueller et al., 2009). These studies indicate that for patients with an injured corpus callosum and elderly adults without any visual feedback, there were severe defects regarding the functional coordination control between two hands (B., 1975; Moes et al., 1995; Mueller et al., 2009). However, the coordination control performance between the time and grip strength during task operation in these studies cannot be measured quantitatively, and the changes in bimanual coordination control cannot be analyzed further in terms of time and grip strength with both hands.

Therefore, a modified evaluation method should be developed that can quantitatively and simultaneously measure the bimanual grip force control and coordination function, which can be used to determine the capacity of bimanual grip force coordination control and to facilitate an understanding of the operational influence of aging on the neuromuscular system in terms of bimanual grip force performance. Thus, the purpose of this study was to establish an evaluation method to investigate the influence of aging on the maximum grip force output and capacity of coordination control with grip force using two hands.

2. Methods

2.1. Participants

Twenty-one healthy young (23.05 ± 3.15 years old; 6 female and 15 male) and ten healthy elderly adults (80.5 ± 4.53 years; 2 female and 8 male) were recruited from college and community settings. The criteria for inclusion were being healthy with no disease that would affect the functions of upper limbs and hand movement, no cognitive dysfunction and being able to execute the test procedures and follow researchers' instructions. All of the participants signed informed consent forms, and the dominant hand was defined as the one used for writing. For the healthy elderly group, the criteria also required the participants to undergo a Mini-Mental Status Examination (MMSE), and a minimum score of 24 or higher (normal cognitive function) was required (Folstein et al., 1975). The exclusion criteria included the following: uncomfortable symptoms, including pain in performing tasks with grip force. This test was approved by the Institutional Review Board of National Yang-Ming University.

2.2. Research device and data processing

Two dynamometers that can measure a 980 Newton force were used to evaluate the maximal voluntary contraction tests and grip force in the bilateral hand isometric grip force coordination control task. Data sampling was performed through data interception using a software program written using LabVIEW, 2009 edition, with the sampling frequency set to 10 Hz. The strength performance of the bimanual grip force of the bilateral hand isometric grip force coordination control tasks performed by all subjects was displayed on a 22-inch LCD screen to provide visual feedback of the summation strength performance of the bilateral hands.

2.3. Experimental procedures and positioning

Each subject sat in a safety-height adjusted chair and faced the operation platform and LCD screen before positioning their bilateral upper limbs in a testing position so that the test of grip force tasks could be executed comfortably and fixed their forearms with forearm supporters so as to avoid the abnormal compensation movements that would affect the correctness of the values measured during the test. The testing position for each subject was the shoulder joints in 30°–40° adduction in the horizontal plane and 40°–50° flexion in the sagittal plane, with the elbow in 100°–110° flexion so that fingers could be easily flexed for 90° to hold the dynamometer. Then, the subject was asked to execute two tests: maximal voluntary contraction (MVC) tests and bilateral hand isometric grip force coordination control tasks.

2.4. Maximal voluntary contraction test

The MVC test was used to determine the capability of the muscle maximal contraction of both hands for subjects. The test was executed by asking the subjects to grasp the dynamometer of the system with their maximum grip forces and maintain the force for 6 s (Coombes et al., 2008). The MVC in this research was defined as the maximum grip force exerted during 2–6 s of the maximum grip force period selected from three MVC tests (Shinohara et al., 2003), which were executed during the resting time of 60-s intervals when conducting this test (to avoid muscle fatigue) (Bigland-Ritchie et al., 1983). After deciding the MVC value through maximal voluntary contraction tests in both hands, we chose the lower MVC value between two hands and calculated the 10%, 20%, and 40% MVC three force values as the light, middle and heavy target grip forces for bilateral hand isometric grip force coordination control tasks.

2.5. Bilateral hand isometric grip force coordination control task

This testing involved the evaluation of the functional activities requiring the most coordination of bimanual hand grip force during daily life that need to be simultaneously controlled and implemented by bimanual coordination (Jaric et al., 2005, 2006). The bilateral hand isometric grip force coordination control task was mainly used to mimic daily activities requiring the coordination performances of grip force between two hands (i.e., opening a container), which can be helpful in investigating the coordination control of bilateral hand grip force with both hands (Flanagan and Wing, 1995; Krishnan and Jaric, 2010). In this task, the force was applied alternatively and continuously between the two hands at the same time (Fig. 1). After verbal cueing, each subject started to grasp the dynamometer lightly with his/her dominant or non-dominant hands, increasing the grip force gradually to the target force by one hand and then stabilizing and maintaining the grip force output of the target force. The subject was asked to release the hand grasping the dynamometer tightly and grasp the dynamometer slowly with the other hand tightly, trying to maintain the summation of the force produced by dominant and non-dominant hands the same as the target grip force. Once one hand was released completely, the subject had to stabilize the grip force output of the target force and then continue to perform grip force alternation between the dominant and non-dominant hands for three rounds. The first and second rounds of the three rounds were used to familiarize the subject with this task. Therefore, the last round of the three rounds was selected for data analysis. During this process, we provided the total force (dominant handgrip force + non-dominant handgrip force) combination curve of both hands on the screen to enhance the attention of the subject and provide visual feedback on bimanual resultant force variation to improve the task execution performance. The total force is obtained