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RESEARCH NOTE

Age-Related Differences in the Stabilization of Important Task Variables in Reaching Movements

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Empirical evidence suggests that the ability to stabilize important task variables of everyday movements by synergistically coordinating redundant degrees of freedom decreases with aging. The aim of the current study was to investigate whether this decrease may be regarded as a characteristic that also applies for the control of multiple task variables. We asked younger and older subjects to repeatedly reach towards and grasp a handle, while joint angle movement of the arm was recorded. The handle constrained final hand position and final hand orientation. Movement variability was analyzed during movement execution by using the uncontrolled manifold method. Results showed that hand orientation was less stabilized in younger than in older subjects. We conclude that aging changes the stability of important task variables. These changes may lead to decreased stability in some task variables, as reported in the literature, but also to increased stability in other task variables.

Keywords: aging, kinesiology, motion analysis, motor behavior, motor control, older adults

In a recent study by Verrel and colleagues (Verrel, Lövden & Lindenberger, 2012) it was found that, in pointing movements, older subjects stabilize hand position less than younger subjects. Decreased stabilization of a hypothetically important task variable with age was also found in other studies (Olafsdottir, Zhang, Zatsiorsky & Latash, 2007; Shinohara, Scholz, Zatsiorsky & Latash, 2004), which could show that in multifinger force production tasks, the decline in motor performance with aging was accompanied by a decrease in the stability of hypothetically important task variables. These authors used the uncontrolled manifold hypothesis (Latash, Scholz & Schöner, 2007; Scholz & Schöner 1999) for their analysis. In the concept of the uncontrolled manifold hypothesis, the amount of movement variability, which is not related to a hypothesized task variable (V_{ucm}), represents the flexibility in the synergistic coordination of the degrees of freedom (DoF; Latash et al., 2007, Latash, Levin, Scholz & Schöner, 2010). On the other hand, variability in task-relevant

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directions (V_{orth}) directly influences the performance outcome. The flexibility in the synergistic coordination (V_{ucm}) in relation to the variability in task-relevant directions (V_{orth}) gives an index about the stability of the motor system against perturbations (Latash et al., 2007). In the literature, a synergy index (i.e., V_{ucm}/V_{orth}) greater than one is interpreted as the motor system is stabilizing a respective task variable (Latash, et al., 2007). Latash and colleagues (Latash & Anson, 2006; Latash et al., 2010) highlighted the importance of this synergy index to describe accurate motor performance in older people. Verrel and colleagues (2012), for example, found that, toward the end of the movement, this synergy index was decreased in older people, whereas endpoint variability was not influenced. However, it is not clear, whether, in the presence of multiple, hypothetically important task variables, the decrease in the synergy index with age is a general characteristic that can be seen for all task variables, or whether some of the task variables may be even more strongly stabilized. Gera and colleagues (2010) could show that younger people were able to synergistically stabilize multiple task variables without interfering between them. The question arises, whether the strategy to stabilize multiple task variables differs between age groups.

The aim of the current study was to investigate the stability of hypothetically important task variables in a reach-to-grasp movement, in younger and older people. For this purpose we investigated the variability of hand orientation and hand position in younger and older subjects, when reaching toward a cylindrical target. Variability of the task variables, as well as variability of the effector system (i.e., joint angle variability of the arm) was analyzed. A general decrease in the synergy indices would support previous findings (Olafsdottir et al., 2007; Shinohara, et al., 2004; Verrel et al., 2012), suggesting a decreased ability of older subjects to stabilize important task variables. An increase in the stability of one task variable with age, however, would suggest that aging may also lead to increased stabilization of hypothetically important task variables. This would imply different control strategies to stabilize multiple important task variables between younger and older people.

Subjects and Methods

Eleven younger (mean age: 25.5 ± 3.4 years) and eleven older (mean age: 66.3 ± 3.1 years) subjects participated in the study. They were paid for participation and gave written informed consent before participation. The subjects were not aware of the purpose of the study. All subjects were right hand dominant as determined by the Edinburgh Handedness Inventory (Oldfield, 1971).

A detailed description of the experimental set-up can be found in Krüger, Eggert and Straube (2011). Briefly, subjects repeatedly had to reach towards and grasp a cylindrical target, which was positioned within reaching distance in front of them (see Figure 1A). To provoke the most natural movement, no demands concerning movement speed or reaction time were made. The target could be placed at three possible positions and changed its location between every reaching movement (trial). To minimize within-subject between-trial variability due to differences in the initial position, starting position was carefully defined by the set-up. The size of the target forced the subjects to grasp it with the whole hand, and not just with two fingers (see Figure 1B). Due to its geometric properties, the cylindrical target

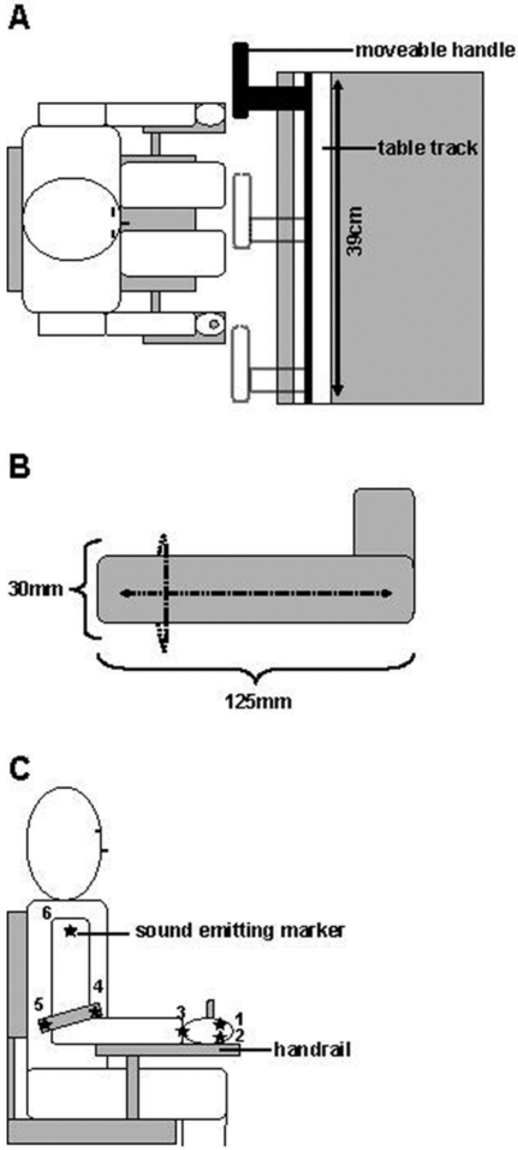

Figure 1 — Experimental set-up and apparatus. A) View of the experimental set-up from above. The black solid bars represent one of the three possible positions of the moveable target. Dashed bars show the other two possible target positions. B) The positions of the six ultra-sonic sound-emitting markers are depicted. The starting position of the dominant right arm was defined by grasping a wooden lever attached to the handrail. C) The cylindrical target is depicted with its length and depth. Parts A and C are reprinted from *Clinical Neurophysiology*, 122/4, Krüger, M., Eggert, T., & Straube, A., Joint angle variability in the time course of reaching movements, 759–766, Copyright (2011), with permission from Elsevier.

constrained final hand orientation and hand position in two out of three possible axes, each. Four blocks with 30 trials in each block were recorded (120 trials). Each experimental block consisted of 10 trials of each handle position, arranged in a pseudo-random order to avoid predictability of the handle position. Between the blocks a break of a maximum of five minutes was offered to avoid fatigue.

Arm movement was recorded by an ultra-sonic sound emitting system (Zebris Medical, Isny, Germany). Recording frequency was 33 Hz for each of the six markers, which were attached to the subject's arm to record joint angle motion in the seven DoF of the arm (see Figure 1C). Shutter glasses (Translucent Technologies, Toronto, Canada) were used to prevent visual online control of the reaching movement. The opening and closing of the shutter glasses was triggered by the movement onset of the first marker (i.e., at the basal joint of the index finger). As soon as the subjects started their movement, the shutter glasses occluded and thereby prevented visual online control of the movement. The first contact with the handle was monitored by recording the electrical resistance between the subject and the handle (sampled at 1 kHz).

The data analysis is described in detail in a recent article by our group (Krüger, Borbély, Eggert & Straube, 2012). Briefly, the joint angles of the arm were computed from the marker position using a three segment rigid body model. Joint angles were expressed as seven consecutive Cardan angles in the following order: two angles for the wrist (vertical, horizontal), two for the elbow (torsion, flexion), and three for the shoulder (torsion, horizontal, vertical). The vector containing these seven joint angles is hereafter referred to as arm posture. In addition, orientation of the hand in space (i.e., 3D) was defined by the orientation of the plane defined by the three markers on the hand and wrist. The orientation was specified in Helmholtz coordinates relative to the external world. The hand position in space was defined by the center of the two markers of the hand in world fixed Cartesian coordinates. The full temporal resolution of the joint angle motion was reduced to ten equidistant sampling points between movement initiation and movement end. Before estimating the 7×7 covariance matrix of the arm posture for reaching movements between fixed starting position and fixed target position, a correction of the joint angle trajectories for small intertrial variations of movement duration and of the actual starting position of the arm was calculated. After this correction, the covariance matrix of the starting position (first sample) reduced to zero and was not considered in further analytical steps. Thus, the covariance matrix of the joint angles was analyzed at nine equidistant sampling points during the movement.

Two overall measures were computed to examine the amount of variability of the reaching movements on joint angle level during the time course of movement execution: (1) square-root of the mean within-subject variance, averaged across the seven joint angles of the arm (in the following referred to as: "standard deviation of arm posture"), and (2) square root of the mean within-subject variance of the task variable averaged across its three dimensions ("standard deviation of the task variable"). These overall standard deviations were calculated separately for each subject, and sampling point. Hand orientation and hand position were considered as the two task variables in the current study. Target position was not considered as a factor in the further analysis, since recent work (Krüger, et al., 2012) showed that the overall standard deviations of both the task variables, and the effector variables (i.e., joint angle variability) did not differ across handle positions.

The uncontrolled manifold analysis was calculated as described in detail in Krüger et al. (2012). At each sampling point total joint angle variance was partitioned into two subspaces, with respect to the task variables: (1) the subspace of differential joint angle changes that did not affect task variables (irrelevant variance, normalized to the number of DoF in that subspace: V_{ucm}), and the orthogonal subspace (relevant variance, normalized to the number of DoF in that subspace: V_{orth}). Subsequently, the synergy index was calculated as the ratio between V_{ucm}/V_{orth}. All computations were performed using Matlab 7.9.0 (Mathworks, Natick, USA).

Statistical analysis was calculated using SPSS 9.0. A repeated measurement ANOVA was calculated with age-group (younger and older subjects) as the between factor, and sampling point as the repeated factor for the following dependent variables: (1) standard deviation of arm posture, and: (2) standard deviation of the task variable (for hand position, and hand orientation, each), (3) V_{ucm}, (4) V_{orth}, and (5) V_{ucm}/V_{orth}. The critical value for significance was set at $p < .05$. Greenhouse-Geisser adjustment was made, if the sphericity assumption was rejected by Mauchly's sphericity test. Variance data were tested for normal distribution with the Lilliefors-test. Data were normally distributed for all of the above mentioned factors at almost all sampling points.

Results

Neither standard deviation of arm posture, nor standard deviation of hand position or hand orientation differed between younger and older subjects, neither at movement end, nor across the time course of movement execution. The uncontrolled manifold analysis of joint angle variability with respect to the task variable hand position did not show any significant main effect or interaction involving the factor age group. Both age groups stabilized hand position throughout the whole time course of movement execution (i.e., $V_{ucm}/V_{orth} > 1$). The synergy index (V_{ucm}/V_{orth}) was greatest at movement start and decreased until the midst of the movement. Afterward the index was stable at a level of 2.

The uncontrolled manifold analysis with respect to the task variable hand orientation revealed that hand orientation, too, was stabilized by both age groups throughout the whole time course of movement execution. The ratio of V_{ucm}/V_{orth} was stable at the beginning of the movement and increased continuously in the second half of the movement (see Figure 2A). However, older subjects stabilized hand orientation more strongly than younger subjects, as indicated by a significant main effect of age group ($F(1,19) = 4.885$, $p = .040$). No other effects reached the level of significance.

Older subjects showed less variance than younger subjects within the subspace of the uncontrolled manifold (V_{ucm}) in the first half of the movement and more variance than younger subjects in the second half of the reaching movements. This qualitative observation was supported by a significant interaction of age group × sampling point ($F(2.515,47.823) = 3.502$, $p = .029$; see Figure 2B). Pairwise comparison showed significant differences between the two age groups for the first two sampling points (#1: $F(1,19) = 5.507$, $p = .030$; #2: $F(1,19) = 4.861$, $p = .040$). For the task-relevant variance (V_{orth}), neither the main effect of the factor age group nor the interaction effect age group × sampling point reached significance.

The main effects of sampling point were significant for each dependent variable and were in line with recent observations by our group (Krüger et al., 2011; Krüger et al., 2012).

Discussion

The objective of the current study was to investigate the stability of hypothetically important task variables in a reach-to-grasp movement in younger and older people. Similar to the findings of Verrel and colleagues (2012) joint angle variability of the arm, as well as variability of hand position, and also hand orientation were not increased in older subjects. Hence, younger and older subjects performed the reaching movements with the same quality of performance. No age-related differences were found for the stabilization of hand position in our experiment. However, younger and older subjects differed in the strength of stabilizing hand orientation during movement execution, with older subjects stabilizing hand orientation more strongly than younger subjects. Leaving aside the sign of this difference, the observed change of synergy index was similar to other observations in so far that it was caused by a change of the task irrelevant variance. Verrel et al. (2002) found a decreased synergy index for stabilizing hand position in older people caused by decreased task-irrelevant variance. Domkin and colleagues (2002), who investigated the changes in the structure of movement variability with practice, also found a decreased synergy index due to decreased task-irrelevant variance. In general, a change of the synergy index without strong changes in the task-relevant variance may indicate a switch in the control strategy concerning the minimization of task-irrelevant variance.

The differences to the findings of Verrel and colleagues (2012), who found decreased stabilization of hand position in older subjects, may be due to the fact that the reaching task used in our experiment forced subjects to control multiple task variables. In contrast, the pointing movement used in the study by Verrel and colleagues constrained only one task variable, namely final hand position. Empirical evidence suggests that the motor control system is able to simultaneously stabilize multiple, hypothetically important task variables (Gera, et al., 2010). In a recent study (Krüger, et al., 2012) we could show that the motor control strategy differs in the stabilization of multiple, hypothetically important task variables, depending on the constraints applied by the movement task. The finding that younger and older subjects differ in the strength of stabilizing hand orientation, but not hand position, suggests that younger and older subjects adapt their motor control strategy differently to multiple task constraints. This suggests that the decreased ability of older subjects to stabilize important task variables, as reported in the literature (Olafsdottir et al., 2007; Shinohara et al., 2004; Verrel et al., 2012), is not a general characteristic associated with normal aging, but is influenced by the movement task. In the presence of multiple task constraints, older people may show different strategies in controlling important task variables, as when the movement task requires the control of one task variable, only.

We conclude that aging changes the stability in the control of hypothetically important task variables. These changes may lead to decreased stability in some task variables, but also to increased stability in other task variables.

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