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Original Research Report

Anticipatory Motor Planning in Older Adults

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Abstract

Objectives: The end-state comfort (ESC) effect represents an efficiency constraint in anticipatory motor planning. Although young adults usually avoid uncomfortable postures at the end of goal-directed movements, newer studies revealed that children's sensitivity for ESC is not fully in place before the age of 10 years. In this matter, it is surprising that nothing is known about the development of the ESC effect at older ages. Therefore, the aim of the present study was to examine the development of anticipatory motor planning in older adults.

Method: In 2 experiments, a total of 119 older adults (from 60 to 80 years old) performed in an unimanual (Experiment 1) and a bimanual version (Experiment 2) of the bar-transport-task.

Results: Across both experiments, the propensity of the ESC effect was significantly lower in the old-old (71–80 years old) as compared with the young-old (60–70 years old) participants.

Discussion: Although the performance of the young-old participants in the unimanual and bimanual task was comparable to what has been reported for young adults, the performance of the old-old participants was rather similar to the behavior of children younger than 10 years. Thus, for the first time, evidence is provided for the decrease of the ESC effect in older adults.

Keywords: Ageing—Anticipatory motor planning—End-state comfort effect—Older adults—Ontogenetic development

Anticipation during goal-directed grasping is essential to solve everyday tasks, where it has been shown that the way in which people grasp an object depends on what they plan to do with this object in the near future. One way to examine such anticipatory motor planning abilities is the so called end-state comfort (ESC) effect. This effect was first described by Rosenbaum and colleagues (1990) and since its discovery 25 years ago, a large body of research has shown the significance of the ESC effect on motor planning in healthy adults across a variety of tasks (see Rosenbaum, Chapman, Weigelt, Weiss, & Van der Wel, 2012 for review). Only a few studies focused on the developmental nature of the ESC effect (see Wunsch, Henning, Aschersleben, & Weigelt, 2013 for review). These studies investigated children of different ages and reported a distinct developmental trajectory across childhood, with the ESC effect reliably present only at the age of around 9–10 years, depending on different task constraints (e.g., Stöckel, Hughes, & Schack, 2012; Thibaut & Toussaint, 2010; Wunsch, Weiss, Schack, & Weigelt, 2015). Given the developmental nature of the ESC effect, as revealed from research on children, it is surprising that (to the best of our knowledge) until today no study has examined the ESC effect at the other end of the life span, that is, in older adults.

In general, there is broad evidence for motor performance deficits in older adults, including (visually guided) movements that rely on the interaction of cognitive and motor systems, like manual reaching actions or gait and balance tasks (see Seidler et al., 2010 for review). These motor performance deficits are often attributed to a general slowing (i.e., reduced processing speed) and a higher movement variability in older adults as a result of a shift in control mechanisms with age (i.e., from lower-level automatic to higher-level attentional control) along with functional and structural changes in the brain; and accompanied by decreasing cognitive capacities for task performance (Huddleston, Ernest, & Keenan, 2014; Salthouse, 2000; Seidler et al., 2010). In this regard, it can be expected that ESC planning performance declines in older adults, because cognitive processes contribute to the generation of appropriate motor plans, like in reaching and gasping.

For children, it has been argued that the development of motor planning skills relates to the development of cognitive skills (e.g., Rosenbaum, Carlson, & Gilmore, 2001; Rosenbaum et al., 2012; Wunsch et al., 2013). Specifically, a major growth spurt at the age of 5–6 years has been associated with the maturation of a number of cognitive skills (Stöckel & Hughes, 2015a, 2015b; Weigelt & Schack, 2010), such as response inhibition in go/no-go tasks (Bell & Livesey, 1985), response inhibition in the Wisconsin Card Sorting Task (WCST; Chelune & Baer, 1986), following abstract task rules (Diamond & Taylor, 1996), and changing from a previously acquired action-effect mapping to a new stimulus-response association (Eenshuistra, Weidema, & Hommel, 2004). Hence, the interdependencies between the development of higher cognitive skills and the maturation of anticipatory motor planning skills may be stronger than has been assumed in the past. These and other cognitive skills are supported by a number of executive functions, such as cognitive flexibility, goal setting, attentional control, and information processing (Anderson, 2002). It has been shown, that executive functions develop at young ages (Huizinga, Dolan, & van der Molen, 2006; Welsh, Pennington, & Groisser, 1991). Nevertheless, the issue of whether or not the development of higher cognitive skills is associated with the maturation of anticipatory motor planning skills is still not resolved. A number of researchers suggest that the acquisition of intellectual and perceptual-motor skills in general (e.g., Rosenbaum et al., 2001) and more specifically the sensitivity for ESC and executive functions is closely linked to the development of higher cognitive capacities (Stöckel et al., 2012; Weigelt & Schack, 2010; Wunsch et al., 2013). Support for this suggestion comes from a recent study by Stöckel and Hughes (2015a), who demonstrated specific relationships between ESC planning and executive planning as well as between manual dexterity and working memory, and inhibition in 5–6-year old children. Other researchers, however, have argued that children's bias toward selecting a grip that minimizes initial discomfort cannot be taken as direct evidence that they have a deficit in "thinking ahead," and therefore, a deficit in higher cognitive capacities (van Swieten et al., 2010).

With regard to the development of cognitive skills in older adults, it is generally accepted that a number of cognitive capabilities decline as people grow older (Levy, 1994). Here, it is important to consider that tests of executive functions activate a distributed network of mainly frontal (as well as nonfrontal) brain regions (Duffy & Campbell, 2001). At the same time, human aging is associated with neurodegeneration, which can be observed in structural changes and volume loss of the frontal brain regions (Head et al., 2004; Salat, Kaye, & Janowsky, 1999; Tisserand et al., 2002; see Anderton, 1997, 2002 for an overview). As a consequence, cognitive capacities, especially executive functions, also decline with age, as has been shown in a variety of studies, for example, for inhibition (Shilling, Chetwynd, & Rabbitt, 2002; West & Alain, 2000), working memory (Salat, Kaye, & Janowsky, 2002), planning and problem solving (Andrés, 2001; Brennan, Welsh, & Fisher, 1997), and cognitive flexibility (Bowles & Salthouse, 2003; Kramer, Hahn, & Gopher, 1999; Meiran, Gotler, & Perlman, 2001). Reviews about the decline of cognitive functions in older adults were provided by Hedden and Gabrieli (2004) and by Park, O'Connell, and Thomson (2003).

Based on the assumption that a number of human planning skills are supported by intact executive functions (Lezak, Howieson, Loring, Hannay, & Fischer, 2004; Miyake et al., 2000), anticipatory motor planning skills should decrease as people grow older. Therefore, the aim of the present study was to examine the development of anticipatory motor planning in older adults. A total of 119 older adults (ranging in age from 60 to 80 years) performed in a unimanual (Experiment 1; Rosenbaum et al., 1990) and a bimanual version (Experiment 2; Weigelt, Kunde, & Prinz, 2006) of the bar-transport-task. Because higher cognitive planning costs are associated with the coordination of bimanual movements (cf. Hughes & Franz, 2008; Kunde & Weigelt, 2005; Stöckel & Hughes, 2015a), the influence of age on the ESC effect should be larger in the bimanual bar-transport task (high-cognitive demands) than in the unimanual bar-transport task (low-cognitive demands), especially under conditions in which two different action plans have to be generated to coordinate different movements of the two hands (Janssen, Crajé, Weigelt, & Steenbergen, 2010; Swinnen & Wenderoth, 2004). As a result, participants are expected to perform worse with increasing age when cognitive planning costs are high, based on the decline of cognitive functions in older adults (as reviewed by Hedden & Gabrieli, 2004 and by Park et al., 2003).

Groups of young-old participants (60–70 years old) and groups of old-old participants (71–80 years old) were instructed to reach with their preferred hand, or simultaneously with both hands, for one or two bars, each lying horizontally on two cradles, and to insert the one bar or both bars into a target hole in front of the apparatus.

Consistent with previous studies, the initial hand orientation (overhand vs underhand grasp) adopted while grasping the bar was assessed. With regard to the decline of executive functions (Hedden & Gabrieli, 2004; Park et al., 2003) and the volume loss in frontal lobe brain regions (Anderton, 1997, 2002), it was hypothesized that task performance would decrease in older people, with a lower sensitivity for ESC in the old-old participants. This effect should be stronger for the (more complex) bimanual task in which the two hands performed simultaneously, as compared with the unimanual task in which only one hand was used.

Experiment 1

Experiment 1 examined whether the decline in executive control with increasing age (Hedden & Gabrieli, 2004; Park et al., 2003) affects anticipatory motor planning in older adults. Therefore, grasp posture planning performance (as signified by the ESC effect) was assessed in a total of 70 older adults between 60 and 80 years by means of the bar-transport-task (Rosenbaum et al., 1990). It was predicted that the ESC effect decreases with increasing age.

Methods

Participants

Seventy older adults between 60 and 80 years (M_{age} = 71.3 ± 5.3 years, 22 women) volunteered in the first experiment. For data analysis, participants were divided into two age-groups corresponding to the decade of their life (group labels were adapted from the Victoria Longitudinal Study; see Hultsch, Hertzog, Dixon, & Small, 1998): 28 young-old (60–70 years old, M_{age} = 65.9 ± 2.8 years, 10 women) and 42 old-old (71–80 years old, M_{age} = 75.0 ± 4.6, 12 women) participants. Based on self-report, three participants of the young-old group and two participants of the old-old group were left-handed. All participants had normal or corrected to normal vision, and had no known neuromuscular disorders or any physical limitations of upper limb movements. Prior to participation, informed consent was obtained. The experiment conformed to the Declaration of Helsinki.

Task and procedure

Participants completed a short questionnaire, asking for handedness, movement limitations, and the number of days of physical activities for at least 60 min a day over the last week, not only including sports, but cycling, working in the garden, taking a walk, and so forth (according to Booth, 2000).

Afterwards, participants had to complete the bar-transport-task similar to the one originally developed by Rosenbaum and colleagues (1990). A wooden bar, 20 cm long and 2.5 m in diameter, with one black and one white end rested horizontally on two cradles, 15 cm above the table so that grasping was not restricted by the table surface. Different to the original task version, there was only one target at midline in front of the apparatus (not two targets on either side, as in the original task). This target was a 5 cm high, black cylindrical container, with a diameter of 3.0 cm, which was placed 10 cm in front of the supports (Figure 1A).

Participants started the experiment in an upright standing position, with both hands placed besides their body, and both palms facing their upper legs, 10 cm away from the table. They were instructed to securely grasp the bar with their preferred hand and to insert the designated end (either the black or the white end) into the target hole, and to then put their hands back to their sides and wait for the new instruction. Meanwhile, the experimenter brought the bar back to the initial position, only using a pincer grip on one end of the bar to avoid observational learning effects. Participants had to complete a total of six trials, in three of which they had to insert the white end, and three in which they had to insert the black end, resulting in a total of three trials requiring an initial overhand grip (i.e., habitual palm-down grasp posture; overhand condition) and three trials requiring an initial underhand grip to end up comfortably (i.e., critical palm-up grasp posture; underhand condition).

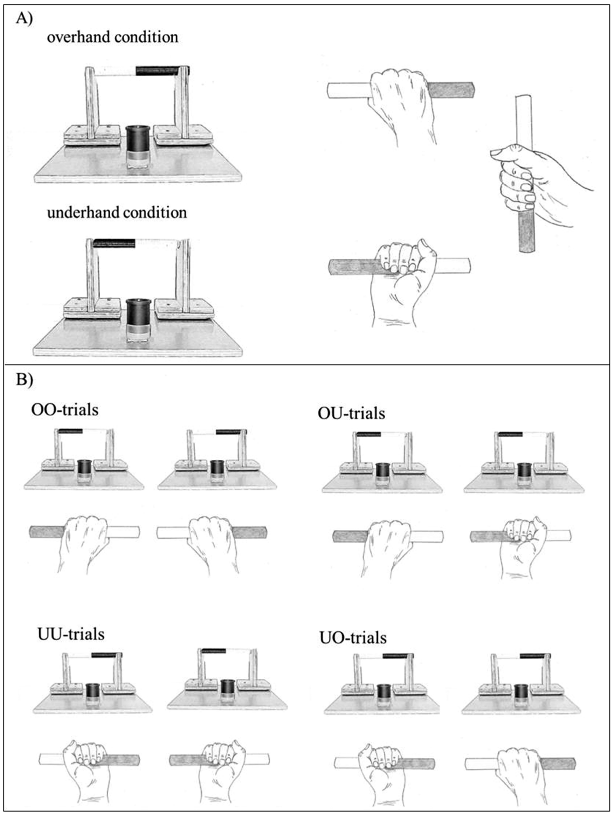

Figure 1. (A) Depiction of the unimanual (both experiments) and (B) the bimanual (Experiment 2) bar-transport-task. All depicted grasps show the predicted grasping type for reaching end-state comfort when inserting the black end of the bar into the target hole.

The initial bar orientation (i.e., black end pointing to the right) remained the same throughout the experiment, but was counterbalanced across participants. The order of trials was randomized. There were no familiarization trials prior to testing. Importantly, participants were never constrained in their grip selection. They were free to reach for the bar using either an overhand or an underhand grip. Typically the entire experiment lasted between 5 and 10 min. A video camera was placed beside the table, digitally recording the whole experiment for subsequent analysis of individual grip choice.

Data analysis

For each planning condition (underhand, overhand), the proportion of trials, in which the bar was grasped using an ESC compliant grasp posture (i.e., resulting in a thumb-up posture at the end of the movement; Figure 1A) was determined as a measure of ESC sensitivity. Because the data did not meet the assumptions of parametric statistical analysis (i.e., homogeneity and normal distribution), the proportion of trials in which ESC was satisfied was determined for each participant, and normalized using an arcsine transformation. Data were analyzed using a planning condition (overhand vs underhand) × age group (young-old vs old-old) analysis of variances (ANOVA) with age group as between-participant factor, followed by Sidak adjusted post hoc simple comparisons whenever warranted. The measure of physical activity was included as a co-variable to control the data for the influence of physical activity on executive functioning (cf. Berryman et al., 2014; Bherer, Erickson, & Liu-Ambrose, 2013). In order to test for the relation between age and ESC sensitivity, partial correlations controlling for physical activity were used. Although, statistical tests were performed on the transformed variables, the back-transformed results are reported and displayed for a better illustration of the data. Data are reported as the mean (*M*) together with corresponding 95% confidence intervals (CI). Partial eta squared values and Cohen's *d* are reported as measures of effect size.

Results

Figure 2 shows the proportion of ESC-conform grasps in each condition separated by age group. On average, the young-old group adopted an ESC-conform grasp in 92.8%, CI [86.7%, 97.1%] of the trials in the habitual overhand condition and in 87.1%, CI [71.4%, 97.0%] of the trials in the critical underhand condition. The old-old group adopted an ESC-conform grasp in 94.9%, CI [90.7%, 98.0%] of the trials in the habitual overhand condition and in 67.6%, CI [52.1%, 81.3%] of the trials in the critical underhand condition. Data analysis revealed a significant main effect for planning condition, $F(1, 67) = 8.09$, $p = .006$, $\eta_p^2 = .11$, indicating a lower ESC sensitivity in the underhand (*M* = 78.1%, CI [67.0%, 87.5%]), as compared with the overhand condition (*M* = 93.9%, CI [90.5%, 96.7%]). Moreover, the analysis revealed a significant age group × planning condition interaction, $F(1, 67) = 4.02$, $p = .05$, $\eta_p^2 = .06$. Post hoc pairwise comparisons revealed the lower ESC sensitivity in the underhand as compared with the overhand condition to be significant ($p < .001$, $d = .82$) only in the young-old, but not in the old-old group ($p = .38$, $d = .34$). The difference between the two age groups in the underhand condition did not reach significance ($p = .07$, $d = .38$).

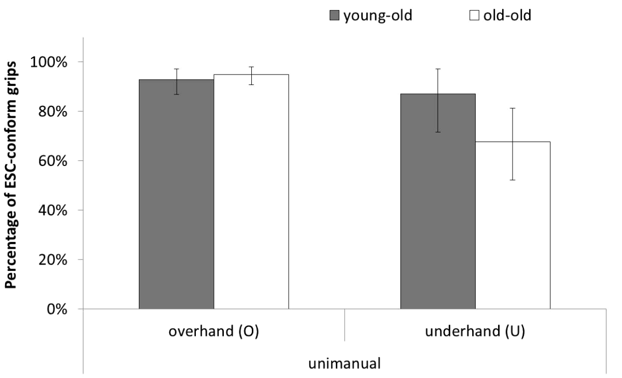

Figure 2. Percentage of ESC-conform grips in Experiment 1 compared between young-old (gray bars) and old-old (white bars) participants. Error bars show 95% confidence intervals.

The proportion of ESC-conform grasps was negatively related to participant's age in the underhand ($r = -.24$, $p = .03$), but not in the overhand planning condition ($r = .12$, $p = .17$).

Discussion

The goal of Experiment 1 was to examine the developmental nature of the ESC effect at the other end of the life span, that is, in older adults. As the results show, the sensitivity toward comfortable end postures declines with increasing age, especially when habitual and goal-directed systems require the adoption of different grasps. The young-old participants were more likely reverted to habitual grasp behavior (i.e., overhand grip), probably due to reduced cognitive capabilities in general (Levy, 1994), and executive functions in particular (Salthouse, Atkinson, & Berish, 2003). Motor planning is said to draw on frontal lobe functions and therefore, the volume loss in frontal lobe areas of the human brain with increasing age (see Anderton, 1997, 2002 for an overview) is likely to affect anticipatory motor planning skills along with a decrease in executive control (Huizinga et al., 2006; Welsh et al., 1991).

Notably, the sensitivity for ESC in the old-old participants was as low as demonstrated previously for children of 6–7 years of age (e.g., Scharoun & Bryden, 2013; Stöckel & Hughes, 2015b; Thibaut & Toussaint, 2010; for an overview see Wunsch et al., 2013), while ESC sensitivity of young-old participants conforms to figures of healthy adults (Rosenbaum et al., 1990; for an overview see Rosenbaum et al., 2012).

Experiment 2

The results of Experiment 1 revealed a decline of anticipatory motor planning skills in older adults. This was confirmed by a reduced ESC sensitivity in the group of old-old participants in the critical underhand as compared with the habitual overhand condition and a lower proportion of ESC-conform grasps with increasing age. In Experiment 2, the decline of anticipatory motor planning skills in older adults is further examined by varying task complexity using different versions of the bar-transport task. To this end, two new groups of young-old and old-old adults within the same age-ranges were tested and performed the bar-transport-task in four different bimanual conditions, in addition to the two unimanual conditions (similar to Experiment 1). Because higher cognitive planning costs are associated with the coordination of bimanual movements (cf. Hughes & Franz, 2008; Kunde & Weigelt, 2005; Stöckel & Hughes, 2015a), it is hypothesized that the influence of age on the ESC effect is larger in the more complex, bimanual bar-transport task (high-cognitive demands) than in the unimanual bar-transport task (low-cognitive demands), especially under conditions in which two different actions plans have to be generated to coordinate different movements of the two hands (Janssen et al., 2010; Swinnen & Wenderoth, 2004). Specifically, it has been shown that while young and older adults perform identically when the same action plan can be used for both hands, older adults exhibit greater movement variability than young adults under conditions when different action plans have to be generated for the two hands (Wishart, Lee, Murdoch, & Hodges, 2000). In this regard, it is further predicted that anticipatory motor planning performance is lowest when the generation of two different action plans is required for the two hands, in order to end comfortably with each hand.

Methods

Participants

Forty-nine older adults between 60 and 80 years (M_{age} = 70.6 ± 3.2, 24 women) volunteered to take part in Experiment 2. For data analysis, and similar to Experiment 1, participants were divided into two age-groups corresponding to the decade of their life: 25 young-old (60–70 years old, M_{age} = 65.4 ± 3.4, 12 women) and 24 old-old (71–80 years old, M_{age} = 75.8 ± 3.0, 12 women) participants. Based on self-report, all participants were deemed to be right-handed, had normal or corrected to normal vision, and had no known neuromuscular disorders or any physical limitations of upper limb movements. Informed consent was obtained prior to participation in the experiment. The experiment was approved by the institutional review board at Rostock University, and conformed to the Declaration of Helsinki.

Task and procedure

The apparatus and procedure was the same as in Experiment 1, with two exceptions: First, participants had to perform the bar-transport-task in each condition with their right and left hands, with the unimanual trials being performed before the bimanual trials. Second, while in unimanual trials only one bar was positioned on the support cradle, for the bimanual conditions, two bars were positioned on two identical supports and the participants were asked to reach for the two bars with both hands simultaneously and to place the instructed ends into the two targets (Figure 1B). Mimicking the procedure employed by Weigelt and colleagues (2006) and Stöckel and Hughes (2015a), participants had to perform eight bimanual trials with the two bars being either in the same orientation (e.g., both black ends pointing to the right) or different orientations (e.g., one black end pointed to the left and one to the right). Participants performed a total of sixteen trials, comprised of the four bar start-orientations (both black ends to the right, both black ends to the left, one black end to the left and one to the right, and vice versa) and the two bar end-orientations (both black ends down, both white ends down), with each trial performed twice. The individual conditions were presented in a randomized order. The order for bar orientation (same vs different) was blocked and counter-balanced across participants, while the order of color combination (black vs white) was variable within these blocked conditions. Based on the start orientation of the two bars and the instructed final bar orientations, it was possible to differentiate between four object end orientation conditions in the bimanual trials: (1) both objects required overhand grasp postures to satisfy ESC (OO trials), (2) ESC was satisfied by the adoption of an overhand grasp posture for the left bar and underhand grasp posture for the right bar (OU trials), (3) ESC was satisfied by an underhand grasp posture for the left bar and an overhand grasp posture for the right bar (UO trials), and (4) ESC was satisfied by grasping both bars with underhand grasp postures (UU trials). Data of conditions 2 and 3 were pooled and analyzed together as *mixed trials*, referring to the different action plans required to end up with both hands in a comfortable position (i.e., in a thumb-up posture).

Data analysis

Data analysis for the unimanual trials was similar to Experiment 1: a planning condition (underhand vs overhand) × hand (left vs right hand) × age group (young-old vs old-old) ANOVA was conducted, with age group as a between-subject factor. For the bimanual trials, a planning condition (OO trials vs UU trials vs mixed trials) × age group (young-old vs old-old) ANOVA was conducted, with age group as a between-subject factor.

Results

Unimanual trials

For each condition and group, the proportion of ESC-conform grasps in the unimanual trials is depicted in Figure 3 (left side). The main effects for planning

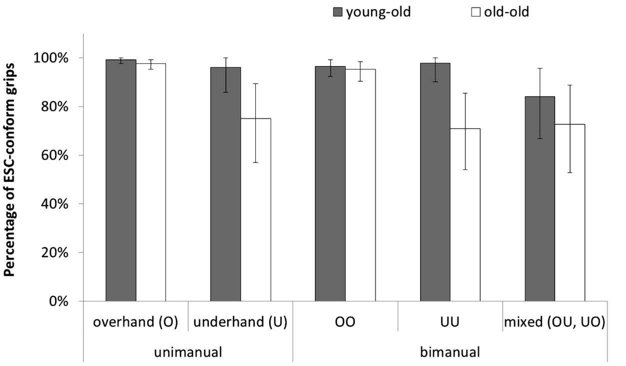

Figure 3. Percentage of ESC-conform grips in Experiment 2 for unimanual and bimanual trials of the bar-transport-task compared between young-old (gray bars) and old-old (white bars) participants. Error bars show 95% confidence intervals.

condition, $F(1, 47) = 12.12$, $p = .001$, $\eta_p^2 = .21$, and for age group, $F(1, 47) = 7.01$, $p = .01$, $\eta_p^2 = .13$, were both significant. Accordingly, participants demonstrated lower ESC sensitivity in the underhand conditions ($M = 87.5\%$, CI [77.5%, 94.9%]), as compared with the overhand conditions (M = 98.5%, CI [97.2%, 99.4%]). Also, the young-old group (M = 98.0%, CI [94.1%, 99.8%]) used significantly more ESC-conform grasps than the old-old group (M = 89.0%, CI [81.7%, 94.5%]). Importantly, the interaction of planning condition × age group reached significance, $F(1, 47) = 3.93$, $p = .05$, $\eta_p^2 = .08$. Post hoc pairwise comparisons revealed significant differences between the young-old group and the old-old group in the underhand trials ($M_{\text{young-old}} = 96.1\%$, $M_{\text{old-old}} = 74.9\%$; $p = .02$, $d = .70$). There were no significant effects involving the factor hand. Moreover, the proportion of ESC-conform grasps was negatively related to participant's age for both unimanual planning conditions (both $r < -.26$, both $p < .05$), indicating a decline in ESC sensitivity with increasing age.

Bimanual trials

For each condition and group, the proportion of ESC-conform grasps in the bimanual trials is depicted in Figure 3 (right side). There was a significant main effect for planning condition, $F(2, 94) = 7.09$, $p = .001$, $\eta_p^2 = .13$. Post hoc comparisons only revealed the difference between the bimanual overhand condition ($M = 95.9\%$, CI [92.8%, 98.1%]) and the mixed condition ($M = 78.6\%$, CI [65.7%, 89.1%]) to be significant ($p = .003$). The main effect for age group was significant, $F(1, 47) = 6.27$, $p = .016$, $\eta_p^2 = .12$, revealing more ESC-conform grasps in the young-old ($M = 93.9\%$, CI [87.6%, 98.1%]), as compared with the old-old group ($M = 81.3\%$, CI [71.8%, 89.3%]). However, the interaction of planning condition × age group was also significant, $F(2, 94) = 3.71$, $p = .03$, $\eta_p^2 = .07$, indicating that the global age effect differs between planning conditions. Post hoc pairwise comparisons revealed the differences between young-old and old-old participants to be significant only for the bimanual UU condition ($M_{\text{young-old}} = 97.8\%$, $M_{\text{old-old}} = 71.0\%$; $p = .001$, $d = .97$). In the young-old group, UU and mixed planning conditions differed significantly from each other ($p = .02$, $d = .65$). In the old-old group, ESC sensitivity was reduced in the UU ($p = .01$, $d = .83$) and mixed conditions ($p = .02$, $d = .81$), as compared with the OO condition in this age group. Moreover, the proportion of ESC-conform grasps was negatively related to participant's age for the bimanual UU condition ($r = -.39$, $p = .003$), indicating a decline in ESC sensitivity with increasing age.

Discussion

Experiment 2 investigated the decline of motor planning abilities in older adults by varying task complexity using unimanual and bimanual versions of the bar-transport task, and therefore placing low-cognitive versus high-cognitive demands on participant's performance, respectively. When the two groups of older adults performed under unimanual task conditions, the results of Experiment 1 were replicated. Accordingly, the old-old participants showed significantly less ESC planning in the critical underhand trials, as compared with the young-old participants, indicating a decline of motor planning skills with increasing age. This was further supported by the results of the bimanual task conditions. When an underhand grasp had to be selected for both hands and when the two hands had to select two different grasps under the mixed condition, the old-old participants were less likely to reach ESC. However, performance decreased also for the young-old participants in the mixed conditions.

This specific pattern of results provides further evidence for the decline of motor planning abilities in older people, as revealed by comparing the two tasks of different complexity. Accordingly, the young-old participants were able to select the underhand grasp with the same efficiency than the (habitual) overhand grasp in the unimanual condition, whereas performance already decreased for the old-old participants. Thus, when the cognitive demands of the task were low, only the young-old participants were able to flexibly adopt their grasps to reach ESC. When task complexity was increased in the bimanual version of the bar-transport-task, placing higher cognitive demands on participant's performance, young-old participants were able to flexibly adopt their grasps for as long as the same grasps could be selected for the two hands. In this regard, their performance was similar to those of the young adults (university students) in the study of Weigelt and colleagues (2006). Compared with these young adults and consistent with previous findings (e.g., Wishart et al., 2000), they suffered, however, when two different action plans had to be generated in the mixed conditions (as signified by lower ESC) and two different grasps had to be selected (i.e., an underhand grasp with one hand and an overhand grasp with the other hand), decreasing to similar levels as the old-old participants. It can be concluded that the cognitive costs associated with the present task(s) selectively influence the motor planning abilities in young-old and old-old people, but not in younger adults (Weigelt et al., 2006).

General Discussion

The goal of the present study was to investigate how anticipatory motor planning skills develop at the end of the life span, that is, in older people. Although a number of recent studies highlighted the development of anticipatory planning skills for a variety of object manipulation tasks in young children (Wunsch et al., 2013), until they are fully in place in young adults (Rosenbaum et al., 2012), virtually nothing is known as to how this development continues at old ages. Therefore, a unimanual version (Experiment1) and a bimanual version (Experiment 2) of the well-established bar-transport-task were used to test participant's sensitivity for the ESC effect (Rosenbaum et al., 1990; Weigelt et al., 2006). Consistent with other research in older people, suggesting a decline of executive functions (e.g., Hedden & Gabrieli, 2004; Park et al., 2003) due to a significant volume loss in frontal lobe brain regions (e.g., Anderton, 1997, 2002) and/or a shift in control mechanisms toward higher-level attentional control (Seidler et al., 2010), it was expected that the sensitivity for ESC in object manipulation tasks decreases with increasing age. This effect should be even stronger with higher levels of task complexity during bimanual task performance (high-cognitive demands) than unimanual task performance (low-cognitive demands).

These predictions are fully supported by the present results. For the first time, a decrease of the ESC effect at the other end of the life span, that is, in older people, was demonstrated. When the task required reaching for the horizontal bar in Experiment 1, a significant higher number of young-old (60–70 years old) participants used an underhand grasp and finished the manipulation in a comfortable posture of the hand, as compared with the old-old (71–80 years old) participants. This pattern of results signifies the decrease of anticipatory motor planning skills at old ages. Experiment 2 further corroborated this finding. First, the results of Experiment 1 were replicated, such in a way that the young-old (60–70 years old) participants reached ESC more often than the old-old (71–80 years old) participants in the unimanual trials. Second, the higher task demands during bimanual object manipulation, associated with higher cognitive planning costs, further reduced ESC planning. In both experiments, performance in the object manipulation tasks was significantly correlated with age, that is, older participants were less likely to finish the action in a comfortable posture of the hand(s). Hence, a negative developmental trend for the ESC effect was observed in the present sample of older people. Quite remarkably, the performance of the old-old (71–80 years old) participants was comparable to what has been previously reported for 6–7 years old children (e.g., Wunsch et al., 2013).

At the beginning of the life span, however, the positive developmental trend of the ESC effect has been associated with an increase of anticipatory motor planning skills in young children (Wunsch et al., 2013). Such planning skills are thought to rely on the development of more general cognitive skills (Rosenbaum et al., 2001; Weigelt & Schack, 2010), which are supported by a number of executive functions (Anderson, 2002). In fact, it has been recently shown that children's performance in the bar-transport-task is correlated with their executive planning and working memory performance (Stöckel & Hughes, 2015a). Therefore, it can be argued that, such as children's anticipatory planning skills rely on the development of more general cognitive skills at the beginning of the life span, motor planning suffers in older people, as these cognitive skills decline at the other end of the life span (Levy, 1994). The latter may be a result of the effects of neurodegeneration during human aging (Anderton, 1997, 2002), which especially impairs a number of executive functions in older people (Hedden & Gabrieli, 2004; Park et al., 2003).

An alternative line of argument is that motor planning abilities and executive functions develop largely independent from each other (van Swieten et al., 2010), which assumes motor and executive planning processes to support two separate (control) mechanisms. Considering this separation, the absence of the ESC effect should not be seen as a deficit of "thinking ahead," but rather relates to inefficient motor planning abilities and/or to more general motor skills deficits, as for example, in a number of clinical populations with movement disorders (e.g., Smyth & Mason, 1997). For older people, this would mean that the decrease of the ESC effect is merely based on increasing (possibly rather unspecific) motor planning deficits at the end of the life span, being largely uninfluenced by the parallel decline of cognitive skills. Although this issue cannot be resolved by the present study, deficits of motor planning may only become evident when tasks are sufficiently complex, placing higher cognitive demands on performance, such as when people have to generate two action plans for the two hands and to coordinate two different movements.

Another possible explanation for the present findings would be that the old-old participants plan their actions just as well as the young-old participants, but want to avoid underhand grasps when reaching for the object. It may be that old-old participant, as opposed to young-old participants, find it more uncomfortable to grasp and lift the bar with an underhand grasp than to end the action in a thumb-down position (We thank David A. Rosenbaum for suggesting this alternative interpretation of the results.). To attend to this hypothesis is important, because if true, this would alter the interpretation of the present results. Although this hypothesis cannot be fully ruled out by the present study, in the following, a number of arguments against this alternative explanation are presented.

Quite frankly, comfort ratings about the two types of initial grasps and final postures would have been very helpful to resolve this issue. Unfortunately, comfort ratings were not collected in the present study. But this is also true for most all of the studies that have been published on the ESC effect so far. A noticeable exception is the study by

Rosenbaum and colleagues (1990)—that demonstrated the ESC effect for the first time—from which the authors concluded that participants maximize ESC by avoiding uncomfortable final position, even if this means to tolerate awkward grasp postures in the beginning of the action (cf. Experiment 2 in Rosenbaum et al., 1990). It seems that from this study onwards, researchers have accepted that people strive to maximize ESC without collecting comfort ratings, and to the best of our knowledge, this is also true for the "sister" studies that have investigated the ESC effect at the beginning of the life span (cf. Wunsch et al., 2013). Here, it has been shown that the ESC effect is not fully in place before the age of 9–10 years. The possibility that children may not perceive extreme joint angles as uncomfortable as adults do because of their limber/more flexible limbs has been brought to attention in a recent article by Rosenbaum, Herbort, van der Wel, and Weiss (2014). However, although this explanation appears to be plausible for young children, it may not hold for older people, because their limbs and joints become stiffer as they grow older with significant declines in upper extremity flexibility after 70 years of age (e.g., Shields et al., 2010; Stathokostas, McDonald, Little, & Paterson, 2013). In any case, comfort ratings should be collected in future studies to better address this issue.

There are two more details in the data worth to be considered. The first relates to the "size" of the ESC effect under the critical conditions in the unimanual version of the task. Here, old-old participants adopted an underhand grasp in 67.6% of the trials in Experiment 1 and in 74.9% in Experiment 2. Thus, old-old participants did not avoid underhand grasps per se, since in the majority of the trials they finished the action in a comfortable position, tolerating initial underhand grasp. The second relates to the modulation of the ESC effect depending on task complexity in the bimanual version of the task in the young-old participants. They did not have difficulties to select an underhand grasp with the two hands for as long as the same grasps could be selected for the two hands. When two different action plans had to be generated in the mixed conditions, their performance decreased to a similar extent than those of the old-old participants, hinting to the influence of the higher cognitive demands on motor planning arising from this condition. Hence, while older people are in principle able to adopt underhand grasps, they seem to revert to the selection of habitual overhand grasps when the cognitive demands of the task become higher, a pattern of results, which in fact strengthens the motor planning account. Finally, if older people would actually compare the initial posture with the end posture for differences in comfort, this would be a direct indication of anticipatory planning, irrespective of the result of this comparison (e.g., finding it more uncomfortable to grasp and lift the bar with an underhand grasp than to end the action in a thumb-down position), because this would mean to compare the anticipations of possible events (i.e., different postures) in the future.

Together, the present results point to the decline of anticipatory motor planning skills at the end of the life span. This may be a result of a more general loss of cognitive skills at old ages, a process in which the sanity of executive functions seems to play a critical role. The extent to which motor planning is affected in older people appears to rely on the cognitive costs arising from different levels of (motor) task complexity. To include measurements of cognitive and/or executive functions to examine this hypothesized relationship should be the aim of future research.

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