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ORIGINAL ARTICLE

Higher levels of motor competence are associated with reduced interference in action perception across the lifespan

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Abstract Action perception and action production are tightly linked and elicit bi-directional influences on each other when performed simultaneously. In this study, we investigated whether age-related differences in manual fine-motor competence and/or age affect the (interfering) influence of action production on simultaneous action perception. In a cross-sectional eye-tracking study, participants of a broad age range ($N = 181$, 20–80 years) observed a manual grasp-and-transport action while performing an additional motor or cognitive distractor task. Action perception was measured via participants' frequency of anticipatory gaze shifts towards the action goal. Manual fine-motor competence was assessed with the Motor Performance Series. The interference effect in action perception was greater in the motor than the cognitive distractor task. Furthermore, manual fine-motor competence and age in years were both associated with this interference. The better the participants' manual fine-motor competence and the younger they were, the smaller the interference effect. However, when both influencing factors (age and fine-motor competence) were taken into account, a model including only age-related differences in manual fine-motor competence best fit with our data. These results add to the existing literature that motor competence and its age-related differences influence the interference effects between action perception and production.

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Introduction

Successful social interaction involves the anticipation of our interlocutor's actions (von Hofsten, 2004). This ability is assumed to be based on shared representations for perceived and produced actions (Flanagan & Johansson, 2003; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1997). Because of this common basis, action perception and production elicit bi-directional influences on each other when performed simultaneously: While concurrent and incongruent action perception and production interfere with each other, the opposite is true for concurrent and congruent perception and production (e.g., Brass, Bekkering, & Prinz, 2001). Furthermore, action perception and production are influenced by motor experience (Roberts et al., 2016) and age (Diersch, Cross, Stadler, Schütz-Bosbach, & Rieger, 2012). In this study, we explored the influence of age-related differences in manual fine-motor competence on the interference effect in simultaneous action perception and production.

Previous research has shown that action perception is modulated by a concurrent action production. This results in interference effects in cases in which perceived and produced actions do not match (Jacobs & Shiffrar, 2005; Kilner, Paulignan, & Blakemore, 2003). For instance, Hamilton, Wolpert, and Frith (2004) asked participants to lift boxes of different weights. At the same time, they were asked to make judgments about the heaviness of objects lifted by an actor. Participants perceived objects lifted by the actor to be lighter when they themselves lifted a heavy box and heavier when they lifted a light box. In the same vain, action perception is facilitated by a corresponding and simultaneously produced action (e.g., evaluation of movement durations: Hecht, Vogt, & Prinz, 2001; discrimination of hand postures: Miall et al., 2006). Similarly, action perception can facilitate (Edwards, Humphreys, & Castiello, 2003; Ménoret, Curie, Portes, Nazir, & Paulignan, 2013) or interfere with a concurrent action production (Brass, Zysset, & Von Cramon, 2001; Wohlschläger & Bekkering, 2002). For example, Brass et al. (2001) asked their participants to perform finger movements, which were either congruent or incongruent with simultaneously observed finger movements. The authors reported facilitation (i.e. shorter reaction times in participants' finger movements) in congruent trials and interference (i.e. longer reaction times) in incongruent trials.

Most commonly, these bi-directional effects are explained through a shared representational ground of perceived and produced actions ("common-coding approach"; Hommel et al., 2001). This approach assumes that similar motor programmes as those needed to produce actions are activated during action perception and planning (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Iacoboni et al., 1999; Léonard & Tremblay, 2008; Marty et al., 2015). In line with this, action perception and production are mediated by the activity of the sensorimotor system (Valchev, Tidoni, Hamilton, Gazzola, & Avenanti, 2017). For instance, transcranial magnetic stimulation (TMS) applied over sensorimotor sites during action perception modulates motor corticospinal excitability in accordance with the perceived actions (Aglioti, Cesari, Romani, & Urgesi, 2008; Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995; Urgesi, Moro, Candidi, & Aglioti, 2006). Consequently, in cases in which the motor programmes activated by concurrent action perception and production differ they interfere with each other. More precisely, because the sensorimotor system is already tuned in for a certain action when producing it, the concurrent perception of a different action interferes with this movement preparation. Similarly, if the sensorimotor system is engaged in action perception, the preparation and execution of a different action interferes with the concurrent action perception (Blakemore & Frith, 2005).

In line with this view of a common representational ground for action perception and production, better abilities in producing an action go hand in hand with higher skills in perceiving that action. On the behavioural level, adults with a particular motor expertise, such as figure skating (Diersch et al., 2013) or tennis (Farrow & Abernethy, 2003), predicted the correctness of a partially occluded movement continuation more precisely than novices. In the same vain, participants were more accurate in anticipating action goals when observing video recordings of their own actions than recordings of other persons' actions (Knoblich & Flach, 2001; Knoblich et al., 2002). Even a brief motor training in the respective action already enhances accuracy and speed of anticipating the action goal (Hecht et al., 2001; Möller, Zimmer, & Aschersleben, 2015). On the neural level, the activity of sensorimotor brain regions during action perception varies with the observer's previous motor experience (Catmur et al., 2008; Catmur, Walsh, & Heyes, 2009; Heyes, 2010; Press, Heyes, & Kilner, 2011). More specifically, the sensorimotor system shows stronger activity during the observation of actions, for which one has first-hand motor experience compared to actions, for which one has only observational/visual experience (e.g., dancers: Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard 2006; volleyball and tennis players: Balser et al., 2014; pianists: Haueisen & Knösche, 2001; Haslinger et al., 2005; biologically possible vs. impossible actions: Stevens, Fonlupt, Shiffrar, & Decety, 2000). Taken together, these behavioural and neural studies suggest that action perception is highly dependent on the participants' level of motor expertise for the specific actions.

However, the ways we perceive actions are not only influenced by the observer's previous motor experience; they are also subject to developmental change. For instance, accuracy of action anticipation (Diersch et al., 2012), imagery (Personnier, Kubicki, Laroche, & Papaxanthis, 2010; Personnier, Paizis, Ballay, & Papaxanthis, 2008; Saimpont, Mourey, Manckoundia, Pfitzenmeyer, & Pozzo, 2010; Skoura, Papaxanthis, Vinter, & Pozzo, 2005), and the perception of one's own action range (Gabbard, Caçola, & Cordova, 2011) become less precise in older adults. Of a particular interest to the current study is that these age-related differences in action perception follow a similar developmental trajectory as do changes in motor competence during late adulthood (Haywood & Getchell, 2005; Houx & Jolles, 1993; Kauranen & Vanharanta, 1996). That is, increasing age is accompanied by less precise motor planning (Reuter, Behrens, & Zschorlich, 2015) and reduced sensorimotor control of actions in older adults (Seidler & Stelmach, 1995).

Hence, in accordance with the common-coding approach (Hommel et al., 2001), one can hypothesise that the above-mentioned age-related differences in action perception (e.g., Diersch et al., 2012) are merely driven by age-related differences in motor competence and not by other age-related factors (hereinafter referred to as age), such as the decrease of processing speed, working memory, or inhibition (Maylor, Birak, & Schlaghecken, 2011; Park, Hedden, Davidson, Smith, & Smith, 2002). Lower levels of motor competence in later adulthood are associated with changes in the cortical representation of sensorimotor information (Karni et al., 1998; Matsuzaka, Picard, & Strick, 2007; Poldrack et al., 2005) and less automated information processing (Rémy, Wenderoth, Lipkens, & Swinnen, 2010; Wu, Kansaku, & Hallett, 2004). These findings lead to the assumption of a higher vulnerability of the sensorimotor system to challenges, such as the simultaneous processing of action perception and production. Furthermore, it can be assumed that lower levels of motor competence are associated with increased interference effects during simultaneous action perception and production, while the opposite is true for higher levels of motor competence.

In line with this, interference effects in concurrent action perception and production vary with prior active experience with specific task-related actions (Roberts et al., 2016; Capa, Marshall, & Bouquet, 2011). In the current study, we aimed to generalise these findings. The driving assumption was that motor experience does not need to be task-specific to result in differences in action perception. To test this assumption, we investigated whether the participants' general fine-motor competence influences the magnitude of interference effects in simultaneous action perception and production. Specifically, our main goal was to explore whether the age-related decrease in manual fine-motor competence translates into a slower anticipation of an action goal during concurrent action production. Furthermore, we explored how this influence of manual fine-motor competence can be compared to the effect of other age-related factors—approximated by the participants' age in years.

To address these two research questions, we adapted a task from Cannon and Woodward (2008) in which participants repeatedly observed a grasp-and-transport action while performing two different distractor tasks. In a motor distractor task, the participants tapped their fingers (finger-tapping condition) and in a cognitive distractor task, they repeated a memorised sequence of letters and digits (memory condition). Crucially, in the finger-tapping condition, participants produced a motor sequence that was different from the perceived manual grasp-and-transport action. Hence, the finger-tapping condition induced unspecific noise to the sensorimotor system and this noise interfered with the simultaneous action perception. In the memory condition, no such motor interference was observed.

Using eye tracking, we assessed participants' (20–80 years) eye movements during all conditions of the above-mentioned task introduced by Cannon and Woodward (2008). As a measure of action perception, we calculated the frequency of anticipatory eye movements to the action goal (anticipation frequency). This measure is a well-established indicator for action perception in children and adults. Anticipatory eye movements indicate the observer's encoding of future states of the observed behaviour (Falck-Ytter, Gredebäck, & von Hofsten, 2006; Gesierich, Bruzzo, Ottoboni, & Finos, 2008; Melzer, Prinz, & Daum, 2012; Rosander & von Hofsten, 2011). They are present during production and perception of simple goal-directed actions (Flanagan & Johansson, 2003). Furthermore, the recruitment of the observer's motor system during action perception is causally related to anticipatory eye movements (Elsner, D'Ausilio, Gredebäck, Falck-Ytter, & Fadiga, 2013). That is, anticipatory eye movements are delayed during the observation of a goal-directed action if the motor area corresponding with the effector limb of the observed action is stimulated via TMS.

In accordance with the results of the original study (Cannon & Woodward, 2008), we expected anticipation frequencies to be reduced in both distractor conditions (finger tapping and memory) compared to a baseline condition without a distractor task. In line with the original study, this reduction was expected to be greater in the finger-tapping than in the memory condition, because the production of an additional action (finger tapping) directly interferes with the perception of another action (grasp-and-transport). Based on previous studies on the development of action perception and motor competence, we expected lower levels of manual fine-motor competence and advancing age to be associated with a greater interference effect of action production onto action perception. Finally, we aimed to compare and disentangle the relative contributions of these two influencing factors to the interference effect.

Method

Participants

We included 181 participants between the ages of 20 and 80 years (see Table 1 for a detailed description of the sample). All participants reported normal or corrected-to-normal vision. The local ethics committee approved the study and all participants gave written informed consent. Participants received a reward of CHF 30 for their participation.

Procedure

The current study is part of a larger longitudinal research project on the interrelations between action perception and action production throughout adulthood. The tasks employed in this project were designed to assess participants' oculomotor skills (e.g., smooth pursuit, saccade velocity) and their action perception operationalized via anticipatory eye movements. Furthermore, several control measures, such as the participants' health status, handedness, motor or cognitive skills, were included. Manual fine-motor competence and performance in the eye-tracking task were assessed in two separate lab sessions and two different rooms. The two sessions took place not more than 7 days (range 1–7 days) apart from each other. In the eye-

Table 1 Participants' characteristics

Age range (years)	*N*	Gender (% female)	Handedness	Education
20–29	34	65	46.77 (52.77)	4.29 (1.43)
30–39	33	76	66.06 (50.23)	5.55 (1.54)
40–49	24	50	84.79 (25.33)	5.54 (1.84)
50–59	30	67	56.81 (55.38)	4.77 (2.00)
60–69	37	62	79.06 (38.57)	4.76 (2.01)
70–80	23	48	74.82 (49.61)	4.70 (1.66)

Means and standard errors are reported for handedness and education. Handedness (in % right) was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971). Highest education is reported in the range from 1 = high school to 7 = university

tracking session, the participants were seated in a dimly lit room. Prior to task instruction, the eye-tracking system and the calibration procedure were explained. Instructions for both distractor tasks were given prior to stimuli presentation and were repeated right before the actual distractor task. In the fine-motor competence session, participants were seated in front of the work plate and instructed verbally prior to each subtest.

Eye tracking

Stimuli

The stimuli consisted of a simple grasp-and-transport action, which was repeated three times in one video clip. Each clip started with an actor grasping one of three coloured balls (original size: Ø 7 cm/2.8° × 3.0° visual angle) on the right side of a table and transporting and dropping it into a container (original size: Ø 15 cm, height: 12 cm/8.1° × 6.4° visual angle) on the left side of the table. This action sequence was repeated for the remaining two balls. The total duration of each video clip was 14,840 ms. The three grasping actions (from dropping the ball into the container to touching the ball) lasted 1240, 1960 and 1680 ms. The three transport actions (from touching the ball to dropping it into the container) lasted 1960, 2080 and 2200 ms.

Apparatus

Data were collected with an SR Research near-infrared eye-tracking system with a tracking rate of 500 Hz (Eyelink 1000Plus; SR Research, Canada) using the Experiment Builder Software (SR Research). Every participant was given a nine-point calibration. Stimuli were presented on a 17″ display. The display and the near-infrared lights and the camera were mounted on a movable arm at a distance of 60 cm from the participant.

Design

In a within-subject design, participants repeatedly observed the described grasp-and-transport action in three different conditions (adapted from Cannon & Woodward, 2008; see Fig. 1a): first, all participants watched two video sequences without a distractor task (baseline condition). Gaze behaviour during these trials served as a baseline to assess the participants' action perception without the distraction of any additional task. Subsequently, the participants repeatedly observed the described grasp-and-transport action while performing two different distractor tasks: They either tapped their fingers (finger-tapping condition) or internally repeated a memorised sequence of letters and digits (memory condition). The order of the two latter tasks was counterbalanced between participants. In the finger-tapping condition, participants were asked to repeatedly touch their thumb successfully with every finger of their dominant hand (starting with the little or with the index finger). The order in which to tap was indicated prior to each video sequence. Participants were informed that the speed of their movement was not important, but that they should instead engage in a regular tapping rhythm. In the memory condition, one of the two sequences of digits and letters ("R6C8M"; "5L3T9") was displayed prior to each video clip. The participants were asked to sub-vocally rehearse the sequences while watching the video clip. After two video clips, the participants were asked to verbally indicate the rehearsed sequence followed by the presentation of the second sequence. In every video, a sequence of six action steps was shown (grasp-and-transport of three balls). Therefore, every action step was presented 12 times per baseline condition (2 video clips × 3 balls × 2 action types) and 24 times per distractor condition (2 video clips × 3 balls × 2 action types × 2 sequences). This resulted in 12 baseline trials and 24 trials for every distractor task (Fig. 1a).

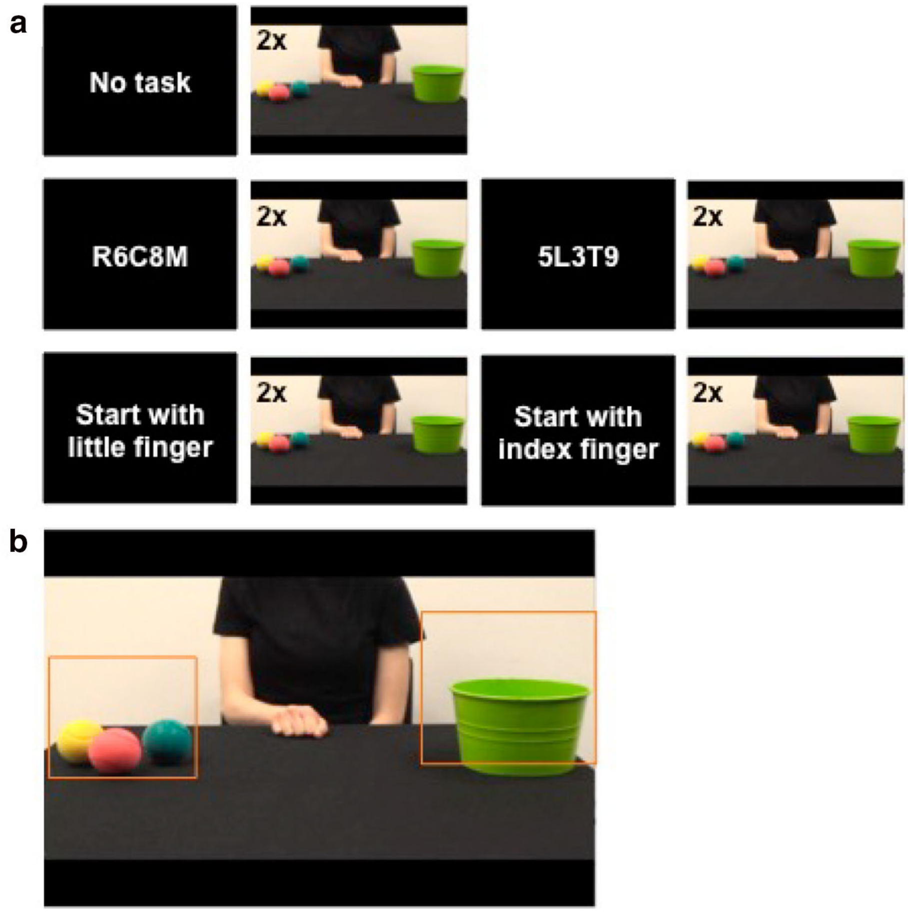

Fig. 1 **a** Research design with baseline, memory and finger-tapping condition. Stimulus video was shown twice per instruction. **b** Still frame of stimulus video with areas of interests (AOI) covering the three balls and the container

Data analysis

Data was reduced with the Data Viewer Software (SR Research). Two areas of interest (AOI) were defined (Fig. 1b): one covering the three balls (ball area; 8.3° × 7.7° visual angle) and one covering the container (container area; 9.7° × 9.6° visual angle). For the grasping action, the ball area served as the goal AOI, and the goal area for the transport action was the container area. To ensure sufficient data quality, only trials in which participants' gaze could be assessed for at least half of the total trial duration were included. Next, the difference in time between the arrival of the actor's hand in the respective goal AOI and the participant's first fixation in the same area was calculated (gaze latency). Using this gaze latency, we calculated anticipation frequencies by dividing the number of trials in which the participants arrived prior to the actor (anticipatory gaze shifts) by the total number of trials that passed the quality criterion (anticipative and reactive gaze shifts). Since different types of actions (i.e., grasp-and-transport), action durations and saliencies induce unspecific variance to the data (Daum, Gampe, Wronski, & Attig, 2016), anticipation frequencies as a more robust measure of action perception were used to account for this variance.

Finger tapping was coded from video. The tapping frequency was obtained by counting participants' touches of finger and thumb, and dividing this number by the duration of the two videos (2 × 14,840 ms). Performance in the memory condition was measured via the number of sequences remembered correctly and ranged from 0 to 2.

Manual fine-motor competence

As a measure of the participants' general level of manual fine-motor competence, we assessed their fine-motor skills with subtests of the Motor Performance Series (Motorische Leistungsserie, MLS; Neuwirth & Benesch, 2011). The computer-based test-battery consists of a work plate with a separate pencil for each hand. Four subtests were included, for which age norms were available for participants between 20 and 80 years (Sturm & Büssig, 1985), and which have been used in previous studies with older participants (e.g., Binder et al., 2016). The selected subtests measure the ability to hold a steady arm-hand position (subtest steadiness), the speed and accuracy of slow (lines) and fast (aiming) arm-hand movements, and the accuracy and speed of fast wrist-finger movements (tapping). Time and number of errors were assessed for every subtask. A composite score of all subtests (according to Platz, Prass, Denzler, & Bock, 1999) was calculated for the dominant hand—as assessed by the handedness test (Oldfield, 1971). The scale of this motor competence score is inverted: The more negative the individual score, the better the participant's manual fine-motor competence.

Results

There were no effects of the order of condition ($p = 0.91$) or action type ($p = 0.23$). Therefore, we collapsed the data across the two orders and action types for all further analysis. On average, sufficient gaze data was obtained for $M = 93.42\%$ (SD = 8.36%) of all trials presented in the baseline condition, for $M = 87.66\%$ (SD = 13.38%) of all trials in the finger-tapping condition, and for $M = 89.82\%$ (SD = 13.21%) of all trials in the memory condition. The number of trials for which sufficient gaze data were obtained did not differ between the two distractor conditions ($p = 0.25$). However, slightly more trials were included in further analyses in the baseline condition compared to the two distractor conditions ($p < 0.001$).

We measured participants' performance in the two distractor conditions to make sure that they followed the task instructions. On average, participants engaged in a tapping frequency of $M = 1.97$ touches per second (SD = 0.68). Participants with a high tapping frequency in action production also showed a high anticipation frequency in action perception during the finger-tapping condition, $r = 0.24$, $p = 0.002$. This makes it unlikely that lower anticipation scores in action perception occurred because participants were shifting their attention from action perception to action production. In the memory condition, participants remembered $M = 1.83$ (SD = 0.43) sequences correctly. The number of sequences remembered did not correlate with the anticipation frequency in the memory condition, $r = -0.02$, $p = 0.79$.

The subsequent analyses are divided into two sections. To replicate previous findings, we compared the raw scores of the anticipation frequencies in all three experimental conditions (baseline, memory and finger tapping). Next, the contributions of age-related differences in manual fine-motor competence and other age-related factors to this result pattern were explored using the difference scores between the baseline condition and the two distractor conditions (see Table 2 for descriptive statistics on the reliability of measures).

Interference effect

First, we explored whether performing a distractor task interfered with the simultaneous anticipation of the action goal, resulting in reduced anticipation frequencies for the two distractor conditions (finger tapping or memory) compared to the baseline condition. A repeated measures ANOVA with a Greenhouse–Geisser correction determined that the mean anticipation frequency differed between the three conditions, $F(2, 360) = 63.571$, $p < 0.001$, $\eta^2 = 0.120$. Post-hoc tests using Bonferroni correction revealed that anticipation frequencies were lower in both distractor conditions (finger-tapping condition: $M = 48.83$, SD = 24.75; memory condition: $M = 63.43$, SD = 22.57) than in the baseline condition ($M = 67.90$, SD = 18.61; finger-tapping condition: $p < 0.001$; memory condition: $p = 0.026$). Furthermore, the anticipation

Table 2 Correlation and reliability of raw scores and difference scores

	1	2	3	4	5	6	7	Mean (SD)	Reliability
(1) Frequency baseline	–	0.30***	0.41***	0.43***	0.41***	0.16*	0.24**	67.89 (18.61)	0.52
(2) Frequency finger tapping	0.30***	–	0.55***	− 0.73***	− 0.31***	− 0.26***	− 0.10	48.82 (24.75)	0.86
(3) Frequency memory	0.41***	0.55***	–	− 0.23**	− 0.66***	− 0.11	0.06	63.43 (22.56)	0.79
(4) Interference finger tapping	0.43***	− 0.73***	− 0.23**	–	0.59***	0.36***	0.26***	19.07 (26.17)	0.87
(5) Interference memory	0.41***	− 0.31***	− 0.66***	0.59***	–	0.24**	0.13	4.46 (22.61)	0.79
(6) Motor competence	0.16*	− 0.26***	− 0.11	0.36***	0.24**	–	0.48***	− 1354.14 (622.43)	–
(7) Age	0.24**	− 0.10	0.06	0.26***	0.13	0.48***	–	–	–

Zero-order correlations of variables of interest (***$p < 0.001$; **$p < 0.01$; *$p < 0.05$). Mean and standard deviation of anticipation frequencies are reported in percentage of trials anticipated (number of trials anticipated per number of trials for which sufficient gaze data could be obtained). Reliability scores refer to Spearman–Brown corrected split-half reliability. Reliability scores for motor competence are not reported because the respective subtests only involved one trial

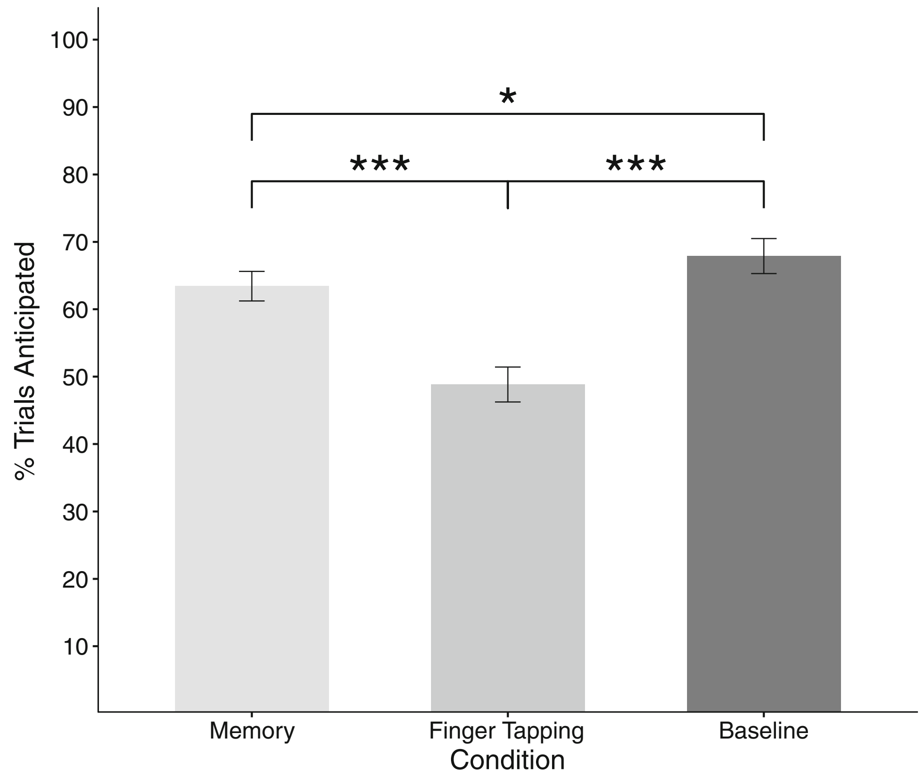

Fig. 2 Percentage of trials anticipated (anticipation frequency) per experimental condition (*$p < 0.05$; ***$p < 0.001$)

frequency in the finger-tapping condition was lower than in the memory condition, $p < 0.001$ (Fig. 2).

Influence of manual fine-motor competence and age on interference effect

Next, we assessed the effects of manual fine-motor competence and age on the interference in action perception in the two distractor conditions. For this, we first calculated separate interference scores for each distractor condition by subtracting the anticipation frequency in the respective distractor condition from the anticipation frequency in the baseline condition. Using R (R Core Team, 2012) and lme4 (Bates, Maechler, Bolker, & Walker, 2015), we performed linear mixed effects analyses, building all subsequent models on a baseline model (Model 1). This model investigated the effect of distractor condition on the interference score. The model included the two distractor conditions (finger-tapping condition and memory condition) as fixed effects and the intercepts for the subjects as random effects (see Table 3 for model overview).

Age

To analyse the extent to which age moderates the effect of distractor condition on the interference effect, we added age and its interaction with distractor condition as fixed effects (Model 2) and compared this model to the baseline model (Model 1). Model 2 provided a better fit with the data than Model 1 (see fit indices in Table 4). This suggests that age moderates the effect of distractor condition on the interference in action perception (Table 3). To further analyse the effects of age in the two experimental conditions, we conducted two separate linear regressions of age on the interference effects for both distractor conditions. Age was only associated with the interference effect in the finger-tapping condition, $F(1, 179) = 13.51$, $p < 0.001$, $R^2 = 0.070$, but not in the memory condition, $F(1, 179) = 3.26$, $p = 0.073$.

Manual fine-motor competence

We investigated the extent to which manual fine-motor competence moderates the effect of distractor condition on the interference score by adding participants' motor competence score and its interaction with distractor condition as fixed effects (Model 3). Model 3 provided a better fit with the data than Model 1 and Model 2 (Table 4). This suggests that manual fine-motor competence moderates the effect of distractor condition on the interference in action perception (Table 3). To explore the effect of manual fine-motor competence in the experimental conditions in more detail, we conducted separate linear regressions of participants' motor competence score on the interference effects in both distractor conditions. Manual fine-motor competence was significantly associated with the interference

Table 3 Linear mixed models

Coefficient	Estimate	SD	*P*
Model 1			
Fixed parameters			
Constant	0.191	0.018	
Condition	− 0.146	0.017	< 0.001
Random parameters			
Subjects	0.034	0.185	
Model 2			
Fixed parameters			
Constant	0.013	0.052	
Condition	− 0.039	0.049	< 0.001
Age	0.004	0.001	0.004
Age × condition	− 0.002	0.001	0.020
Random parameters			
Subjects	0.033	0.180	
Model 3			
Fixed parameters			
Constant	0.965	0.042	
Condition	− 0.235	0.040	< 0.001
Motor competence	0.000	0.000	< 0.001
Motor competence × condition	0.000	0.000	0.014
Random parameters			
Subjects	0.029	0.171	
Model 4			
Fixed parameters			
Constant	0.299	0.086	
Condition	− 0.140	0.082	< 0.001
Age	0.001	0.001	0.453
Age × condition	− 0.001	0.001	< 0.001
Motor competence	0.000	0.000	0.184
Motor competence × condition	0.000	0.000	0.129
Random parameters			
Subjects	0.029	0.171	

Model 1 explores the effect of distractor condition (condition) on the interference score. Model 2 investigates the extent to which age moderates the effect of distractor condition. Model 3 investigates the extent to which motor competence moderates the effect of distractor condition and Model 4 explores the effects of age and motor competence on the interference effects within one model

Table 4 Fit indices and model comparison

	df	AIC	BIC	Log likelihood
Model 1	4	− 59.375	− 43.853	33.688
Model 2	6	− 68.892	− 45.609	40.446
Model 3	6	− 83.530	− 60.246	47.765
Model 4	8	− 81.886	− 50.842	48.943

effect in the finger-tapping condition, $F(1, 177) = 26.56$, $p < 0.001$, and in the memory condition, $F(1, 177) = 10.52$, $p = 0.001$. However, the effect was greater in the finger-tapping condition, $R^2 = 0.131$ than in the memory condition, $R^2 = 0.056$ (Fig. 3).

Age and manual fine-motor competence

To explore the extent to which age and manual fine-motor competence together moderate the effect of distractor condition on the interference score, we compared a full model (Model 4) with the baseline model (Model 1). In the full model, age and its interaction with distractor condition, and participants' motor competence score and its interaction with distractor condition were added as fixed effects. Model 4 provided a better fit with the data than Model 1 (Table 4). When comparing the full model (Model 4) with the Models 2 and 3, Model 4 fit the data better than Model 2. However, it did not provide a better fit with the data than the more parsimonious Model 3. This suggests that Model 3 provided the best fit with the data. Our results therefore indicate that age-related differences in manual fine-motor competence—without taking other age-related factors into account—moderate the effect of the distractor condition on the interference in action perception (Table 3).

Discussion

In the present study, we investigated how the relationship between action perception and action production differs throughout adulthood and how manual fine-motor competence is related to these differences. We used an interference paradigm to assess how the anticipation of an action goal (as a means of assessing action perception) is influenced by simultaneous action production. Furthermore, we were interested in whether and how this influence varies with the observer's manual fine-motor competence and/or age. The findings show that participants throughout the adult life span, from 20 to 80 years, anticipated the goal of a grasp-and-transport action less often when they simultaneously performed finger-tapping movements or mentally rehearsed a sequence of numbers and letters. This interference was strongest with a concurrently performed action. Furthermore, the interference effect increased with participants' advancing age and decreased with participants' increasing manual fine-motor competence. Importantly, manual fine-motor competence elicited a stronger influence on the interference effect in the finger-tapping compared to the memory condition. Moreover, a model including only age-related differences in manual fine-motor competence fit the data better than a model including both fine-motor competence and other age-related factors.

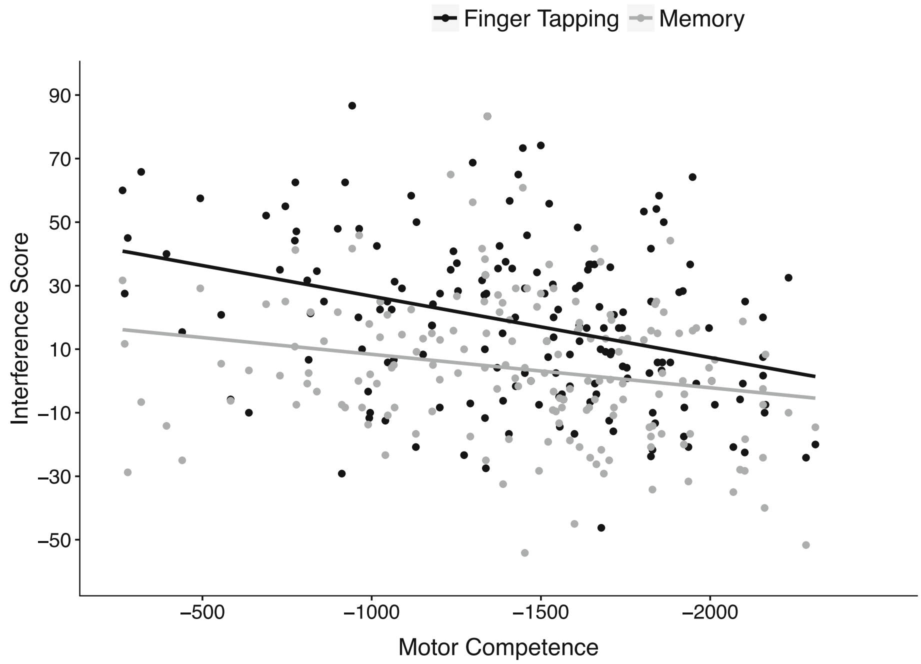

Fig. 3 Relationship between manual fine-motor competence and interference score in both distractor conditions. Note that lower motor competence scores reflect better manual fine-motor competence

Our results are in line with previously reported interference effects of action perception on action production and vice versa (e.g., Catmur, 2016; Hamilton et al., 2004; Kilner et al., 2003; Press, Bird, Walsh, & Heyes, 2008). Importantly, the memory condition did interfere with action perception less strongly than the finger-tapping condition: producing an action while simultaneously perceiving a different action was more challenging than mentally rehearsing a sequence of letters and digits during action observation. That is, although both conditions involved the simultaneous processing of two tasks, they resulted in different effects. Therefore, the reduction in the anticipation frequency in the finger-tapping condition cannot solely be explained by a mere dual-task effect. Hence, there seems to be something uniquely related to the interference in the finger-tapping condition: according to the principle of common-coding, perceived, and produced actions are represented in a shared domain, and overlapping resources are assumed to account for perceiving, imagining, representing, planning, and executing actions (Hommel et al., 2001; Prinz, 1990, 1997). During simultaneous perception and production of two different actions, therefore, two different motor representations are active and simultaneously require cognitive and sensorimotor resources. This results in the reported interference effects.

In our study, the participants' level of manual fine-motor competence influenced the magnitude of interference of action production on the simultaneous action anticipation. This is consistent with previous research on the effects of motor expertise (Calvo-Merino et al., 2006; Diersch et al., 2012) and training (Möller et al., 2015) on action perception and on the interrelations of action perception and production (Capa et al., 2011; Roberts et al., 2016). Our results extend these findings, suggesting that not only motor expertise with a specific task-relevant action, but the more general level of motor competence can affect action perception. In line with this view, participants' manual fine-motor competence influenced their anticipation of the action goal in both distractor tasks. This suggests that different levels of manual fine-motor competence not only shape the participants' action production but also their general ability to anticipate an observed action goal. A simultaneously executed second task interferes with action anticipation, and the more this second task involves the sensorimotor system, the stronger this interference becomes.

In line with previous research (Diersch et al., 2013; Personnier et al., 2008, 2010), our results indicate that the participants' age accounts for some variance in the interference effect between action perception and production. However, in contrast to prior studies, our results suggest that the participants' age-related differences in manual fine-motor competence explain the interference effect better than age in years. Previous studies reporting age differences in action perception often failed to measure the participants' general level of motor competence (e.g., Gabbard et al., 2011). In light of the present results, their findings could be reinterpreted: For example, when evaluating walking distances, older participants reported the walking goal to be further away than younger participants (Sugovic & Witt, 2013). However, not age per se but the participants' own (age-related) walking ability might have influenced their perception of the walking distance. In accordance with this view, in young adults' action planning is influenced by their fitness and the amount of effort they have to put into action production (Jacobs & Shiffrar, 2005). For instance, young participants perceived hills to be steeper when they were tired or out of shape. In this case, their judgments of the steepness of the hill slopes was comparable to those of older adults (Bhalla & Proffitt, 1999). Accordingly, the current state of motor competence substantially impacts the perception of the environment with which to interact.

In our sample, participants' age was significantly associated with their level of manual fine-motor competence ($r = 0.48$, $p < 0.001$). This is in line with previous research showing a decrease of motor competence with advancing age (Haywood & Getchell, 2005; Kauranen & Vanharanta, 1996). Importantly, a model including only manual fine-motor competence as a predictor of anticipation frequency yielded a better fit with the data than a model with both age and manual fine-motor competence included as predictors. Therefore, our findings suggest that the observer's chronological age does not influence the anticipation of an action goal independently of his or her level of manual fine-motor competence. We assume that high levels of motor competence enable motor information to be processed in a more automated and efficient manner (Poldrack et al., 2005; Rémy et al., 2010; Wu et al., 2004). This results in the sensorimotor system being more robust against stressors, such as an interfering distractor task or age-related de-differentiation processes. In line with this notion, action perception does not interfere with simultaneous action production if the action is highly automated (Hardwick & Edwards, 2012). Furthermore, increasing age goes hand in hand with slower automatization of trained actions (Wu & Hallett, 2005), while effects of age on action perception and production are reduced in participants with high task-related motor expertise (Diersch et al., 2013; Krampe, 2002; Schorer & Baker, 2015). Our findings add to this research by associating the more general level of manual fine-motor competence with an increased resistance against interference of a concurrently performed action on the anticipation of action goals.

One issue of the current study, which has to be treated with caution, is the separation of age as an assessment of other age-related factors (such as working memory or attention) and manual fine-motor competence. Specifically, like most assessments of motor competence, the Motor Performance Series (MLS) measures attentional and cognitive processes as well. For the following reasons, it is nevertheless reasonable to conclude that our participants' MLS score is largely determined by their fine-motor skills and only to a small part by other cognitive or attentional factors: First, the MLS shows divergent validity to common cognitive tests (i.e., HAWIE, CFT, STROOP; $r_{max} = 0.35$; Neuwirth & Benesch, 2011) and convergent validity to other indicators of motor competence. For example, the MLS discriminates between motor novices and experts (Kattenstroth, Kolankowska, Kalisch, & Dinse, 2010). In addition, participants' performance in the MLS battery correlates with their resting state sensorimotor connectivity (Seidler et al., 2015) and their grey and white matter volume in the primary motor cortex (Koppelmans, Hirsiger, Mérillat, & Seidler, 2015). Second, our sum score of manual fine-motor competence combines both accuracy and speed measures, and therefore accounts for the speed-accuracy trade-off often associated with advancing age (Forstmann et al., 2011).

In this study, we replicated and extended previous findings (Cannon & Woodward, 2008) across a broad age range. The use of eye-tracking technology and anticipatory gaze shifts as an online measure of action perception is a promising route for further research since it allows the use of comparable measurement techniques across the whole lifespan, from infancy to old age. Furthermore and in particular, longitudinal research is needed to answer open questions, such as whether action perception and production follow similar developmental trajectories. Eventually, this might lead to a research-driven developmental theory on the stability and change of the interrelation between action perception and production (for an example see Loeffler, Raab, Cañal-Bruland, & Rodger, 2016).

Taken together and extending prior work, our results support a common processing system for action perception and production. They furthermore suggest that the general level of motor competence affects action perception similarly across a large age range. That is, independent of the level of manual fine-motor competence, age had no additional effect on the interference between action perception and production. These findings lay an additional cornerstone in understanding the interrelations between action perception and production across the whole lifespan.

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Compliance with ethical standards

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Conflict of interest All authors declare that they have no conflict of interest.

Ethical approval All procedures were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments.

Informed consent Informed consent was obtained from all individual participants included in the study.

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