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Age-related differences in corticomotor facilitation indicate dedifferentiation in motor planning

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ABSTRACT

Efficient motor control requires motor planning. Age-related changes in motor control are well described, e.g. increased movement variability and greater antagonistic muscle co-activation, as well as less functional and less regional specific brain activation. However, fewer are known about age-related changes in motor planning. By the use of TMS we investigated differences in corticomotor facilitation during motor planning in 17 young (25 ± 3 years) and 17 older healthy adults (70 ± 13 years) in a delayed movement paradigm for wrist movements. Motor evoked potentials (MEPs) were recorded for the flexor and extensor carpi radialis during movement preparation of wrist flexion and extension as well as during rest. We found that MEPs were less specifically facilitated by planning in older as compared to younger adults, as indicated by an Age × Condition × Muscle interaction. Young participants showed significantly facilitated MEPs in the respective muscle needed for wrist flexion or extension. By contrast MEPs in older participants were less specifically modulated. We conclude that age relates to dedifferentiated activation of the primary motor cortex already during preparation of distinct movements which might contribute to less efficient motor control in older adults.

Age-related differences in corticomotor facilitation indicate dedifferentiation in motor planning.

Efficient goal directed motor behavior requires motor intentions (Zschorlich and Köhling, 2013) and effective motor planning (Gabbard et al., 2011; Gabbard, 2013; Sterr and Dean, 2008). Planning a motor task includes the integration of information about the motor target and the limb to use. Thereafter, a motor command can be created that is sent to muscles via the primary motor cortex (M1) resulting in limb movement (Hoshi and Tanji, 2000).

It is well known that motor control and motor functioning change with age. The age-related alterations result in more variable as well as slower movements (Diermayr et al., 2011; Mau-Moeller et al., 2013; Vieluf et al., 2013a,b) and increased antagonistic co-activation during the contraction of agonistic muscles (Barry and Carson, 2004; Holl et al., 2015). Moreover, neurophysiological correlates associated with voluntary movement control change with age leading to more diffuse, less functional, and less regional specific brain activation in older compared to younger adults (Berchicci et al., 2012; Heitger et al., 2013; Heuninckx et al., 2005, 2008; Hutchinson et al., 2002; Ward and Frackowiak, 2003). This might result from an age-related reduction of inhibitory mechanisms and deficits in neurotransmission (Maillet and Rajah, 2013; Rajah and D'Esposito, 2005; Seidler et al., 2010).

In comparison to age-related changes in motor control much less is known about age-related changes in motor planning. Yet it seems that not only motor functioning but also motor planning is already subject to age-related changes. For instance, Berchicci et al. (2012) revealed by the use of movement related cortical potentials that older adults show a long-lasting hyperactivity of the prefrontal cortex before action. The authors suggest that this activity reflects highly controlled processing in order to prepare, even simple, motor responses. Furthermore, it has been shown that lateralized readiness potential amplitudes are increased before movement execution in old compared to young adults indicating a reduction of inhibition (Roggeveen et al. 2007, Sterr and Dean, 2008). Moreover, latencies of readiness potentials were found to be prolonged in older adults suggesting an increase of preparation time for movements with increasing age (Ishizuka et al., 1996).

In addition to measuring brain activity shortly before movement execution to learn about motor planning also motor imagery (Chabeauti et al., 2012; Jeannerod, 2001; Munzert et al., 2009) has been used to study age-related differences in action representation, an integral part of motor planning (Gabbard et al., 2011). Motor imagery is characterized by imagining and/or mentally simulating an action without an overt output (Saimpont et al., 2013). A vast number of studies revealed that M1 is activated during motor imagery (for a review see Munzert et al., 2009). Age-related changes in brain activation during motor imagery were found to be similar to those in actual movement. Zapparoli et al. (2013) revealed an over-recruitment of occipito-temporo-parietal areas measured by functional magnetic resonance imaging in older adults.

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Q7 Also Nedelko et al. (2010) found that the regions activated during motor imagery are over activated in older as compared to younger adults, presumably reflecting compensatory mechanisms as in active movement execution (Saimpont et al., 2013). By the use of transcranial magnetic stimulation (TMS) Léonard and Tremblay (2007) investigated age-related changes in motor imagery by testing corticomotor facilitation in the first dorsal interosseous and abductor digiti minimi during motor imagery in older and young adults. The authors revealed that motor imagery is less selective in older as compared to younger adults. Specifically, the authors showed that the capacity for producing subliminal motor activation during motor imagery was largely preserved but that the two target muscles were frequently found to be co-facilitated in the old compared to young participants. The authors propose that age-related changes in the level of cortical inhibition, leading to more widespread facilitation, might have contributed to the differences in facilitation effects in both groups. It remains an open research question, if also during motor planning corticomotor facilitation is less specific with age as it has been shown for motor imagery (Léonard and Tremblay, 2007) and if the reduction of facilitation can also be found for muscles controlling larger scale movements.

With this study we aimed to investigate whether the age-related reduction of facilitation is generalizable to motor planning of discrete movements. This would support the notion of general age-related changes in cortical inhibition during motor planning. In a delayed movement paradigm we elicited motor evoked potentials (MEPs) in the extensor carpi radialis (ECR) and flexor carpi radialis (FCR) shortly before wrist extension or flexion in young and older adults. We hypothesized that young adults would show a strong facilitation of the MEP in the respective agonistic muscle during the planning of the related wrist movement compared to planning the opposite movement or a resting condition (Facchini et al., 2002; Hashimoto and Rothwell, 1999; Kasai et al., 1997; Roosink and Zijdewind, 2010; Zschorlich and Köhling, 2013). Further, following Léonard and Tremblay (2007) we expected this facilitation to be less in older adults, due to a reduction of inhibition and less specific motor planning. Our results will indicate if brain activation during planning of discrete movements is less differentiated with age, as previously found for active movements and motor imagery.

Q8 1. Methods

1.1. Participants

21 younger (21–29 years of age) and 21 older (65–78 years of age) healthy, right handed participants took part in the study. Four younger and four older participants were excluded from the further data analysis because they did not show any facilitation (i.e. larger MEP amplitudes in the experimental conditions as compared to the control condition) in neither the ECR nor the FCR muscles and presumably did not follow the task instructions.

The remaining sample consisted of 17 younger (21–29 years of age, mean age 25 ± 3 years, 4 females) and 17 older (66–78 years of age, mean age 70 ± 13 years, 11 females) individuals. Participants were recruited from the student pool from the Department of Sport Science at the University of Rostock and from local sports clubs offering various activities for seniors. As a consequence of this recruiting strategy all participants can be assumed to be relatively fitter as compared to their peers. All participants took part voluntarily and gave their written consent to the procedure which was approved by the ethics commission of the University of Rostock.

Participants were screened for demographic information that included their educational background, hand dominance, hand usage, weekly hours of sport and leisure time physical activity, as well as their subjective and objective health by the use of a questionnaire (Godde and Voelcker-Rehage, 2010). In addition we investigated the mental status of the older participants by the use of the mini mental state examination (Folstein et al., 1975). All older participants scored higher than 27, and thus did not show any signs of cognitive impairment or dementia. Table 1 shows screening results for each group and statistics for group differences. The groups did not differ with regard to their levels of education, health, weekly hours of handwriting and hand use at leisure time but did differ with respect to their sport score, leisure time walking and/or cycling and typing. All individuals had normal or corrected to normal vision.

1.2. Experimental task and procedure

The setup and task is depicted in Fig. 1. The participants sat in front a 58.4 cm (23 in.) computer screen with their chin placed on a chin rest and their forehead placed against a forehead rest. Their left arm was hanging beside them and they were able to extend and flex their wrist freely. Participants performed a delayed movement paradigm (Georgopoulos et al., 1989) with 60 trials in total. The experiment was controlled by the signal analysis software Diadem (National Instruments, Austin, TX, USA). Two experimental conditions and one control condition were tested with 20 trials each. Each trial consisted of a countdown from 3 to 1 followed by either an arrow (3.5 × 13 cm) pointing to the left (red) or to the right (green) in the experimental conditions or followed by a white unfilled circle (radius = 5 cm) in the control condition. Circle and arrows were presented for 1000 ms each. After 950 ms, thus 50 ms before the arrows disappeared a TMS pulse was given to the subjects (see below for details). In the experimental conditions, i.e. when an arrow was presented, participants were asked to mentally prepare a wrist movement of their left wrist toward the direction of the arrow and to execute such movement as soon as a yellow filled circle appears on the screen. The yellow circle (radius = 5 cm) was presented for 1000 ms and followed by a pause signal consisting of a gray rectangle (4 × 1.5 cm). The left arm was chosen as we assumed that potentially confounding effects of hand usage were less for the left than for the right hand in right handed participants. Previous research revealed that extensive use of hands might buffer age effects on manual dexterity (Reuter et al., 2014; Vieluf et al., 2012, 2013b).

In the control condition the yellow circle did not appear and the pause signal was presented immediately after the white circle. Intertrial intervals were about 5 s, ensuring a minimal interpulse interval of 10 s between two single TMS pulses. As each trial was manually started from the experimenter, participants had the opportunity to indicate the need of longer breaks between trials. After 30 trials, i.e. the first

Table 1
Demographic information per group and results of t-tests for group differences in screening variables. Q2

Variable	Group means and SD				t-Test statistics		
	Young adults (N = 17, 4 females)		Older adults (N = 17, 11 females)		T	df	*p*
	Mean	SD	Mean	SD			
Age	24.94	2.82	69.94	13.12	−13.83	32	**.00**
Education	16.77	2.61	15.47	5.84	0.83	32	.41
Objective health	−0.05	0.68	0.05	0.72	−0.44	32	.66
Subjective health	4.32	0.81	4.21	0.64	0.47	32	.64
Sport score	3.29	0.85	2.00	0.61	5.10	32	**.00**
Leisure time walking and/or cycling	3.31	1.14	4.12	0.93	−2.23	31	**.03**
Typing	16.65	16.83	4.71	7.32	2.68	32	**.01**
Handwriting	5.53	6.63	4.32	11.83	0.37	32	.72
Hand use leisure time	0.45	1.17	1.55	3.11	−1.36	32	.18

Note: Education, years of education; objective health, mean of *z*-score of number of recent illnesses and number of sick days in the last year, a lower score indicates better health; subjective health, mean of 2 items, 5 point scale; sport score (c.f. Baecke et al., 1982); leisure time walking and/or cycling, 1 item, 5 point scale; typing, weekly hours of typing; handwriting, weekly hours of handwriting; hand use leisure time; sum of weekly hours of playing an instrument, handicraft and needlework. Bold numbers indicate significant differences between age-groups.

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