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A kinematic analysis of age-related changes in grasping to use and grasping to move common objects

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ABSTRACT

Grasping is a complex action which requires high-level motor control. Although the impact of aging on grasping has been investigated in some studies, to date little is known as to how the aging process interacts with the purpose of the movement. The aims of the present study were (i) to investigate the effect of aging on grasping movements, and to explore on how this effect is modulated by (ii) the goal of the task, and by (iii) the characteristics of the target such as its location in the visual field, its orientation and its size. Young and elderly adults were asked to grasp to move or to grasp to use objects of different sizes and orientations, presented either in the central or the peripheral visual field. Movement duration did not differ between the two groups. However, elderly participants required a longer approach phase and showed a different grasping strategy, characterized by larger grip aperture and smaller percentage of wrist rotation in comparison to young adults. Elderly adults showed a decrease in accuracy when grasping objects presented in the peripheral, but not in the central visual field. A similar modulation of the kinematic parameters consisting in longer planning and execution phases in the grasp to use in comparison to the grasp to move condition was observed in both groups, suggesting that the effect of aging might be minimized and compensated in more goal-directed tasks.

1. Introduction

Aging implies not only a physical modification of the body structure and muscles (Carmeli, Patish, & Coleman, 2003), but also structural and functional changes of the central nervous system (Lexell, 1997), with consequences for cognition as well as for action and motor control (Ren, Wu, Chan, & Yan, 2013). In particular, changes in hand functionality may affect the way people communicate or respond to the environment, and interact with objects and tools presented in the surroundings. In neurological diseases associated with aging, such as dementia and Alzheimer's disease, patients may show deficits in performing gestures under verbal command, in imitation or in using common objects (Luchelli, Lopez, Faglioni, & Boller, 1993; Ozkan, Adapinar, Elmaci, & Arslantas, 2013; Rousseaux, Rénier, Anicet, Pasquier, & Mackowiak-Cordoliani, 2012). The praxic performance in these studies is commonly assessed using qualitative measurements and accuracy scales (e.g., Rumiati, Papeo, & Corradi-Dell'Acqua, 2010). However, such changes during normal aging are subtle and therefore not easy to detect with observation methods. Kinematic measures thus might be more sensitive to describe the normal progressive loss of hand functionality. Studies that used such methods demonstrated that normal aging alters the performance of goal directed movements, with a decrease in movement speed (Ren et al., 2013; Welford, 1988), longer movement times and deceleration phases (Goggin & Stelmach, 1990; Roy, Weir, Desjardins-Denault, & Winchester, 1999; Shiffman, 1992; Warabi, Noda, & Kato, 1986), a reduced strength (Shiffman, 1992; Voorbij & Steenbekkers, 2001), as well as a general slowing down of the movement (Welford, 1988). However, this impoverishment of the movements is not always observed; several studies reported similar performance for young and elderly adults, both in terms of reaction times and movement speed (Carnahan, Vandervoort, & Swanson, 1998; Riecker et al., 2006).

In addition to the physiological aging being responsible for the overall reduction of hand functionality (Salthouse, 2000), two not mutually exclusive accounts have been put forward to describe age-related changes in aiming movements. First, the decrease in velocity and changes in kinematic parameters have been explained as being due to a conservative strategy that elderly adults might select to complete motor tasks. This strategy aims at limiting the number of errors and at increasing the accuracy of goal directed movements (Bennett & Castiello, 1994; Cole, 1991). In support of this interpretation, Bennett and Castiello (1994) found that, compared with younger adults, elderly participants

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not only took longer in performing reaching and grasping movements but also decelerated for a longer period. Since the deceleration period corresponds to the phase in which the hand approaches the target, the authors interpreted the increase of this movement phase in elderly as being functional to correct eventual errors that may occur in action performance.

The second account suggests that elderly people may show a poor performance in tasks that are new or have a low ecological value for the participants (Bennett & Castiello, 1994). It follows that older participants should show a similar performance to that of young adults in more natural tasks (Carnahan et al., 1998; Varadhan, Zhang, Zatsiorsky, & Latash, 2012). Indeed, Carnahan et al. (1998) reported that elderly adults were actually faster than young adults when grasping stationary or moving blocks across a ramp. However, Bock and Steinberg (2012) did not obtain the same pattern of data when comparing the performance of elderly and young adults using two tasks of different ecological value. Interestingly, in this latter study the action (i.e. to move a lever) was consistent, but in one condition the movement was meaningless and executed under explicit verbal instructions, while in the other condition, it was part of a more complex and ecological action (to play a computer game), with a specific goal (beating the game and winning a small monetary reward). Besides the overall decrement in performance, elderly participants showed specific difficulties in performing the most ecological task. However, a possible criticism to this study is that the observed gap in performance between young and elderly participants may be due to a greater experience of young adults with computer games and electronic devices, rather reflecting an actual age-related decrease in performing more ecological tasks.

To date, most studies in normal aging explored kinematic changes in reaching and grasping meaningless objects, such as geometrical shapes, while the kinematics of tool use have been assessed mainly in adults with apraxia (Hermsdörfer, Hentze, & Goldenberg, 2006; Hermsdörfer, Li, Randerath, Goldenberg, & Johannsen, 2012; Laimgruber, Goldenberg, & Hermsdörfer, 2005; Poizner, Mack, Verfaellie, Rothi, & Heilman, 1990; Poizner et al., 1995; Sunderland, Wilkins, & Dineen, 2011). In the studies on apraxia, the presence or absence of a tool in the patient's hand during the actual execution of the movement (e.g. actual use of the object against pantomime of the use, as in Hermsdörfer et al., 2012; Hermsdörfer et al., 2006; Laimgruber et al., 2005), or the level of concreteness and meaning of the object (common tools or abstract objects) to be manipulated (Sunderland et al., 2011) was considered. A specific assessment of whether the affordance of the object and goal of the task influenced the performance of apraxic patients was carried out by Randerath, Li, Goldenberg, and Hermsdörfer (2009). They had participants grasp common objects, presented with the handles toward or away from the participant's hand, with two different purposes: to demonstrate the use of the object or simply to transport them to a different location. Although no significant differences in movement pace between patients and controls were observed, both groups showed longer reaction times and movement times when using the objects than when only moving them, and faster reaction times when the handle was directed toward rather than away from them. While the latter finding can be due to the increased familiarity and ecological value of the handle facing the participant's hand, the increase in reaction times, when participants used the objects was related to the complexity of the task as it requires more planning.

In the present study, we first we aimed at investigating age-related changes in the kinematics of grasping common tools. Second, we aimed at assessing whether age-related modifications of reaching and grasping kinematic parameters were affected by the goal of the task (to move or to use). To our knowledge, this aspect has not yet been specifically explored in normal aging, even though it does appear relevant given that elderly adults seem to benefit from the ecological value of the tasks (Bennett & Castiello, 1994; Carnahan, Vandervoort & Swanson (1998) Varadhan et al., 2012). For instance, grasping a common tool with the purpose of using it may be more natural and automatic than grasping to move an object, since the affordances of the object may automatically evoke the motor program specifically related to the use of the object (Hermsdörfer et al., 2012; Tucker & Ellis, 2004).

Third, we aimed at assessing whether the intrinsic (e.g. size) or extrinsic (location/orientation) characteristics of the objects modulated possible differences between young and elderly adults. In particular, we were interested in testing whether age-related changes may differentially affect the kinematics of reaching and grasping when eye movements were either directed to the target-object or fixed at a different location with the objects being presented peripherally. Although we typically directly look at objects during reaching and grasping, there are often situations in daily life where we have to reach and grasp objects while looking somewhere else. For instance, we can grasp a mug from the table without moving our eyes away from the book we are reading. In everyday life, errors in reaching toward the peripheral visual field may have unpleasant consequences, like spilling hot water from a mug. A better understanding of our ability to reach and grasp objects in the periphery and possible age-related modulations thus has direct practical implications, also in the light of the fact that vision is affected by physical age, such that visuo-motor processing may hamper the correct execution of reaching and grasping movements toward the peripheral visual field. In particular, it has been shown that the kinematics of the movements can be altered differentially depending on whether only central or peripheral vision is used. Sivak and MacKenzie (1990), for instance, showed that when vision was restricted to central vision only and participants were able to see the target of the action, through ad hoc lenses, changes where observed only, in the grasping component of the movement. By contrast, preventing the use of central but not peripheral vision had a more general and dramatic effect on the kinematics of the movement. For instance, restricting vision to peripheral viewing, the reduced visual information regarding both the characteristics of the target object and its location largely affected both transport and grasping components of the movement, suggesting the importance of central vision for both movement's components.

Furthermore, this manipulation may provide some insights regarding a possible differential involvement of the dorso-dorsal stream (including the intraparietal sulcus bilaterally, and the dorso-lateral fronto-parietal areas) or a ventro-dorsal stream (consisting of left superior temporal/inferior parietal areas) (Buxbaum & Kalénine, 2010; Pisella, Binkofski, Lasek, Toni, & Rossetti, 2006; Rizzolatti & Matelli, 2003) in the process of aging. As previously suggested (Buxbaum & Kalénine, 2010), the dorso-dorsal stream is involved in grasping movements, relies upon the presented visual information regarding the object target of the action (i.e. size and position), is continuously updated and is responsible of online control of movements. By contrast, the ventro-dorsal is specialized for more complex actions, as the use of the object. Rather than being tied to the structural characteristics of the object presented per se, this system relies on the representation of actions associated with the object and its function. Damage to the dorso-dorsal stream, involving superior parietal areas (Buxbaum & Coslett, 1997) and the parieto-occipital junction (Perenin & Vighetto, 1988), alters the ability to perform reaching and grasping movements toward objects presented in the peripheral visual field, while damage to the ventro-dorsal stream may affect the ability to use common objects. Deficits associated with these two streams are well known neuropsychological symptoms such as optic ataxia (dorso-dorsal stream) and ideational or conceptual apraxia (ventro-dorsal stream) often observed as a consequence of brain damage. However, more subtle changes could also appear in aging as a result of age-related morphological changes of the parietal cortex (e.g., Lehmbeck, Brassen, Weber-Fahr, & Braus, 2006), which may differentially affect the dorso-dorsal and/or the ventro-dorsal stream, and their behavioral consequences might be detected using an analysis of the underlying movement kinematics. In particular, the aging processes affecting the dorso-dorsal stream may result in a specific reduction of older adults' performance compared to young