The Association Between Dexterity and Cognitive Functioning in Healthy Elderly: A Kinematic Analysis

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Abstract

Aging has a degenerative effect on hand function and cognition. After the age of 65, most healthy elders experience sensorimotor changes and cognitive declines of various kinds which can make activities of everyday life a challenge. To our knowledge, few studies have investigated the possible interplay between cognitive function and dexterity in the elderly. The purpose of the present study was to assess age-related differences in hand dexterity with the use of kinematic measures on performance of the Purdue Pegboard test. Also, we wanted to evaluate whether executive functions and attention would be associated to the kinematic outcomes in dexterity tasks among elderly adults. Fifteen elderly and fifteen younger adults participated in the study. All participants were tested with a battery of cognitive tests including: Digits Span (Forwards and Backwards), the Stroop test, MMSE, Trail Making Test, BDI, Hand Dynamometer and the Handedness Inventory. Two subtests of the Purdue Pegboard were used to evaluate dexterity. Performance on these two tests was analyzed with a motion capture system (Vicon Motus System) in order to obtain kinematic measurements. The employed kinematic parameters were angular displacement and angular velocities of the angle located between the thumb and index finger of the right hand. Results showed that healthy elderly subjects were slower on dexterity tasks and less performing in the majority of the cognitive tests than younger adults. Correlational analyses for the elderly group showed that tasks measuring attentional mechanisms and executive functioning were significantly associated to kinematic parameters on the easiest dexterity task. While for a more complex dexterity task, the older group showed significant correlations between kinematic parameters and tests of psychomotor control and general mental status. The elderly subjects' performance were slower and presented less variability in movements to complete the dexterity tasks than younger participants. These results tells us that elders execute slower the same dexterity task as compared to younger adults with different movement patters, and the age-related declines in cognitive domains can to a certain degree explain these findings.

Keywords: Normal aging; dexterity; hand movements; kinematics; healthy elders; executive functioning; attention

Abstrakt - Norsk Versjon

Aldring har en degenererende effekt på håndfunksjon og kognisjon. Etter passerte 65 år opplever friske eldre sensomotoriske endringer og kognitive nedgang av forskjellig slag som kan gjøre hverdagslige aktiviteter til en utfordring. Så vidt vi vet er det få studier som har sett på det mulige samspillet mellom kognitiv funksjon og fingernemhet ved bruken av kinematiske målinger på prestasjonen i Purdue Pegboard testen. Dette studiets formål var å vurdere aldersrelaterte forskjeller i fingernemhet ved hjelp av bruken av kinematiske målinger på utførelse av Purdue Pegboard testen. I tillegg ønsket vi å evaluere hvorvidt eksekutive funksjoner og oppmerksomhet ville assosieres med kinematiske resultater på fingernemhetstester blant eldre voksne. Femten eldre og femten yngre voksne deltok i studien. Alle deltakerne ble testet med et batteri av kognitive tester: tallspenn (forlengs og baklengs), Stroop test, MMSE, Trail Making Test, BDI, Hand Dynamometer og Handedness Inventory. To subtester fra Purdue Pegboard ble brukt til å evaluere fingernemhet. Utførelsen av disse to testene ble analysert med et bevegelsesopptakssystem (Vicon Motus System) for å innhente kinematiske målinger. De anvendte kinematiske parametre var vinkelforflytting og vinkelhastighet av vinkelen lokalisert mellom tommel og pekefinger på høyre hånd. Resultatene viste at friske eldre deltakere var langsommere på fingernemhetstester og utviste dårligere ytelse på majoriteten av de kognitive testene sammenlignet med de yngre deltakerne. Korrelasjonsanalyser for den eldre gruppen viste at oppgaver som måler oppmerksomhetsmekanismer og eksekutiv funksjon var signifikant assosiert med kinematiske parametre på den enkleste fingernemhetsoppgaven. Mens for en mer kompleks fingernemhetsoppgave viste den eldre gruppen signifikante korrelasjoner mellom kinematiske parametre og tester som gikk på psykomotorisk kontroll og generell mental status. De eldre deltakernes prestasjoner var langsommere og de utviste mindre variabilitet i bevegelser enn yngre deltakere i den samme fingernemhetsoppgaven. Disse resultatene forteller oss at eldre utfører den samme fingernemhetsoppgaven med forekjellig bevegelsesmønster enn yngre voksne, og at aldersrelatert nedgang i kognitive områder til en viss grad kan forklares av disse funnene.

Nøkkelord: Normal aldring; fingernemhet; håndbevegelser; kinematikk; friske eldre; eksekutiv funksjon; oppmerksomhet

Preface

The present study is part of a larger "umbrella" project of cognitive aging and dementia directed by Claudia Rodríguez-Aranda (the supervisor) at the Department of Psychology in Tromsø. The data obtained in this study is the first step on the analysis of age-related dexterity changes and cognitive declines in aging.

Being the first study, there was the challenge to develop the best protocol for movement analyses by using the Vicon Motus System which was acquired at the Department of Psychology in 2011.The fact to deal with a new technological system was presented to Mari Lise Eriksen (the candidate) from the first meeting with the supervisor. Through a close collaboration between the candidate and the supervisor, the design of this project was achieved after an initial series of pilot trials which took place during the fall 2011. Many adjustments were made all the way throughout the study with frequent assistance from international collaborators of the supervisor from the "EuroMov- Movement to Health laboratory" at the University of Montpellier, France. Further support on practical and technical issues was given by Thomas Nermo and Truls Traasdahl from the University of Tromsø.

The tests in the cognitive battery and the dexterity tasks were chosen based on the supervisors' earlier studies. Recruitment of all participants was done entirely by the candidate. Though, the supervisor helped to establish contact between the candidate and the first elderly participants. All data acquisition was carried out in the laboratory by the candidate. Moreover, the candidate processed all data, both cognitive and kinematic by herself. Specially, we want to mention that the processing of kinematic data was demanding and time consuming. All this work was done by the candidate working closely with the supervisor. The supervisor guided the candidate through the statistical analyses used in this study. Only statistical analyses related to movement parameters were performed by the supervisor due to the expertise needed with these type of data.

The candidate had long considered working with new technology, so having the opportunity to incorporate the use of a new system into psychological research was an exciting and challenging possibility. This project has undoubtedly enriched the candidate by giving her valuable insight into scientific methods in a growing field of research.

Mari Lise Eriksen (candidate　　　　　　　　Claudia Rodríguez-Aranda (supervisor)

The association between dexterity and cognitive functioning in healthy elderly: A kinematic analysis

The rising wave of senior citizens calls for our attention. The age structure in our society is about to change with more people reaching their ninth and tenth decade, and because of this the need for health workers in the future is so great that actions need to be taken in order to meet this requirement (Texmon & Stølen, 2009). Today we live longer, but this prolonged life expectancy has not necessarily gone parallel with sufficient maintenance of cognitive ability (Cahn-Weiner, Boyle, & Malloy, 2002). In fact, the constantly increasing group of elderly in our society is characterized for being extremely heterogeneous and these individuals show a wide range of aging patterns and cognitive abilities. The heterogeneity of elderly persons ranges from clinically diagnosed Alzheimer's Disease (AD) and dementia, to the disease-free elder including also those under the relatively new term of mild cognitive impairment (MCI). MCI refers to those older people who do not meet the criteria for dementia, but still has substantially cognitive impairments as compared to healthy elderly (Aggarwal, Wilson, Beck, Bienias, & Bennett, 2006).

Of importance for the present study is to remark that even among normal elderly there is a huge intra-individual variation in which only few elders will be cognitively healthy and showing little loss in physical functions. This specific group of older adults comprises the so-called successful aging group. However, many other normal elderly will show some type of age-related cognitive decline (Baltes & Lindenberger, 1997; Rowe & Kahn, 1987).

Normal aging and the importance of the parallel study of cognitive and motor changes

The concept "normal" must be first considered. Normal aging has been defined as the absence of disease. However, elders with absolutely no disease is quite uncommon and does not represent the majority (Petersen et al., 1997). Alternatively, one can consider normal aging to be typical aging. Most healthy elders face several challenges for their ability to sustain independent living because they experience cognitive and physical changes that are not necessarily related to disease, but that will affect their daily activities (Forlizzi, DiSalvo, & Gemperle, 2004).

A possible association between physical and cognitive decline in elders has been the topic of several studies, and there seems indeed to be a connection in these deteriorations. Results from many studies have established the existence of a decline in fine motor control paralleled with a decline in cognitive functioning. Some examples follow; Kluger, et al. (1997) found that performance on motor tasks were able to distinguish changes in cognitive status in elderly adults; Cahn-Weiner, Boyle, and Malloy (2002) found that there exist a significant association between functional independence and executive abilities in elderly individuals.

A relevant condition that has been thoroughly studied in the last years is that of frailty and cognitive deterioration. "Frailty" is a heterogeneous syndrome highly prevalent in old age including several medical conditions like musculoskeletal disorders, gastrointestinal diseases and cognitive impairment. It has been linked to outcomes like hospitalization, disability and high risk for falls (Fried et al., 2001; Langlois et al., 2012). Research on the subject of frailty in elders supports the notion that the prevalence of this clinical syndrome can affect cognitive function and physical state (Langlois et al., 2012). Because many of these deteriorations occur within normal ranges of aging it might be fruitful to look at specific physical and psychological changes in healthy elders.

Aging of hand dexterity from a cognitive perspective

In fact, the negative effects of frailty on cognitive functioning are of importance. One specific aspect of this matter relevant for cognitive aging is the relationship between *motor* changes and cognition. We know that sensorimotor changes occurring in normal aging are closely related to the elder’s cognitive status. With advancing age cognitive functions get more involved in sensorimotor processes, and the slowing of behavior becomes apparent (Li & Dinse, 2002; Scherder, Dekker, & Eggermont, 2008). For this reason, several researchers have addressed the relationship between specific cognitive changes and sensorimotor declines. However, in order to restrict the number of variables it is necessary to explore single relationships at a time. As many others, we decided to focus on motor changes and cognition and therefore, sensory changes will not be addressed.

There have been several age-related motor changes well documented in the literature such as slowing of movement (Birren & Fisher, 1995), gait changes (Polcyn, Lipsitz, Kerrigan, & Collins, 1998) and impaired hand dexterity (Carmeli, Patish, & Coleman, 2003). All of these motor changes can be studied in relationship to cognitive function. Though, from the previous examples, hand dexterity, appears to be more tightly associated with cognition as it requires visuo-motor control (Sunderland, Bowers, Sluman, Wilcock, & Ardron, 1999). Hand dexterity is defined as "the skillful manipulation of the hands" (Wiesendanger & Serrien, 2001, p. 228) and this motor ability has practical relevance for every day routines. Impaired hand dexterity can have profound effects on people's everyday life (Ostwald, Snowdon, Rysavy, Keenan, & Kane, 1989), and in spite of its tremendous importance for daily living this is a function less studied from a cognitive/psychological perspective.

Many investigations have studied peripheral anomalies affecting muscles or nerve dysfunction (Bouche et al., 1993; Sorock & Labiner, 1992), but only recently, research has expanded to study central nerve changes such as biological aspects and cognitive decline (Camarda et al., 2007; Verdelho et al., 2010). To our knowledge, few studies have investigated the possible interplay between cognitive function and dexterity in the elderly. For the above reason, we chose to investigate the association between hand dexterity and attentional control in the present study. The rationale for focusing the investigation on this specific association will be presented in the following sections.

Dedifferentiation of function

How can cognitive functioning be connected with dexterity? A possible explanation is related to the dedifferentiation hypothesis (Hedden & Gabrieli, 2004) , which states that aging itself might affect several behaviors at the same time through a so-called common cause, e.g. sensory deficits, motor deficits or declining working memory, and so on. The hypothesis is supported by several studies looking into inter-individual variability with performance on cognitive - and motor tasks. In principle, there are large individual differences in performing varied cognitive tasks. However, this variation within individuals across tasks seems to change with age. Older adults have been found to display more variability than younger adults in reaction times (RTs). The elderly display considerable variation in RTs between trials as compared to younger subjects. This variability on RTs has been found to predict the elders performance on cognitive tasks (Hultsch, MacDonald, & Dixon, 2002). Cooke, Brown, and Cunningham (1989) showed that elderly compared to younger subjects had significantly greater Coefficient of Variation (COV), which is a standardize measure of variability, on several kinematic parameters like movement duration and peak velocity. We think that the variability on performance might possibly be due to a dedifferentiation of function with growing age because this characteristic of aging (i.e., variability) is observed across motor and cognitive functions. However, more experimental data are necessary before any explanation can be put forward.

Normal age-related changes in dexterity

To date, we know that age has a degenerative effect on hand function, especially after the age of 65, with changes like reduced muscle strength and sensibility possibly making the execution of activities of everyday life troublesome (Carmeli et al., 2003; Desrosiers, Hébert, Bravo, & Rochette, 1999; Ranganathan, Siemionow, Sahgal, & Yue, 2001). Some of the causes of deteriorations in hand functioning in aging include disorders common to elderly populations, such as rheumatism and Parkinson's disease (Carmeli et al., 2003). Both intrinsic and extrinsic factors affects manual dexterity, such as malnutrition, genetically determined diseases, osteoporosis, hormonal changes, and reduced physical activity leading to disuse atrophy (Carmeli et al., 2003). Ranganthan, Siemionow, Sahgal and Yue (2001) reported a decline in finger and hand strength, and the maintenance of a steady precision pinch posture in healthy elderly subjects in comparison to young subjects. It has been suggested that a decline in spatial acuity at the fingertips may yield difficulties with tasks involving fine manipulations (Wickremaratchi & Llewelyn, 2006). Also, visual spatial acuity is important for fine precision grip movements, and a decline within this domain often follows old age (Carmeli et al., 2003).

Prominent cognitive changes in aging

Several cognitive declines together with slowing of motor function have been found to degenerate proportionally with advancing age (Baltes & Lindenberger, 1997). It is proposed that attention and those processes supporting control and goal-oriented tasks referred to as "executive functions" (Buckner, 2004) are greatly affected in aging (Kallus, Schmitt, & Benton, 2005). In fact, Kallus et al. (2005) suggested that attention and motor performance are strikingly affected by aging. Attention, is the capacity to direct behavior to a given stimulus, which involves processes that focus, sustain, inhibit and select information (Rogers & Fisk, 2001). Since normal aging affects divided attention, inhibitory processes and working memory, the present study will measure these specific cognitive functions.

The purpose of the present study

In this study, we want to carry out an original approach to understand the association between dexterity and cognitive function in healthy elderly individuals. We will employ a kinematic motion analysis to obtain movement parameters that may help to detect differences in dexterity between old and young persons. Earlier studies on motor function in elders have often been based on simple motoric measures, such as discrimination of object weight, finger tapping and timed one leg standing (Camicioli, Howieson, Oken, Sexton, & Kaye, 1998; Norman, Norman, Swindle, Jennings, & Bartholomew, 2009). Within the field of neurosciences, several investigations have used kinematic techniques to study exclusively performance of hand motor function in the elderly (Cooke et al., 1989; Morgan et al., 1994).

The field of kinematics describes the motion of bodies, and the kinematic motion analysis applied to dexterity will offer the possibility to study how the aging hand moves when performing a fine motoric task. For example, Ketcham, Seidler, Van Gemmert, and Stelmach (2002) used kinematic analyses to establish that elderly subjects were slower and had more variable movements than younger subjects during a speed-accuracy task. These authors suggested that the slowing of movements observed in the elderly group was due to changes in movement amplitude and target size. Morgan et al. (1994) used kinematic analyses to assess a simple targeting movement task. Here, older subjects committed more constant errors and paused more often than the younger subjects, and displayed adductive/abductive asymmetries. Other studies using kinematic analyses of hand movements have discovered that patients with Alzheimer's Disease, compared with healthy subjects, suffers severe changes in gross hand motor activity, such as taking longer time in preparing movements and performing more slowly, and displayed more variability in force during writing (Scherder et al., 2008).

In our study, the focus will lie on fine motor function of the hand, executive functions and attentional control. As previously mentioned attention and executive function are the cognitive abilities most sensitive to decline in normal aging (Buckner, 2004; Milham et al., 2001). Actually, some few studies have found a strong association between executive function and dexterity. A good example is the study performed by Ashendorf, Vanderslice-Barr, and McCaffrey (2009) in which elderly subjects were tested with the Grooved Pegboard Test and their performance was strongly linked to both age, executive functions and processing speed. Various types of pegboards exist to assess fine motor control of the hand. One of these measurements is the Purdue Pegboard which is a well-known measure largely employed in neuropsychological research (Lezak, 1995). The Purdue Pegboard was originally designed for selection and assessment of industrial applicants for labor requiring manipulative dexterity (Tiffin & Asher, 1948). Since that time, the Purdue Pegboard has been employed in various research settings (Desrosiers et al., 1999; Harris, Eckert, Ahlstrom, & Dubno, 2010). Interestingly, the study by Ashendorf et al. (2009) reported a strong association between general cognitive function and the Grooved Pegboard test with healthy older individuals. So far, the Purdue Pegboard has not previously been used analyzed with kinematic analyses.

In the present study, healthy elderly adults underwent two subtests from the widely applied Purdue Pegboard. The original task includes four subtests. However, for our purposes only two of them were administered. The reason for restricting the study to these subtests is due to the extensive amount of motion data that a kinematic analysis produces. The "inserting pins task" and the "assembly task", as they were named in this study, were the two subtasks from the Purdue Pegboard that were undertaken. The former being more of a test on speed and accuracy of dexterity, the latter is a task where cognitive demands are high and speed and accuracy are crucial for performance on the task. Further description of these tasks is presented in the Method section below.

Thus, the Purdue Pegboard task was analyzed as usual by counting the number of pins and other units inserted in a specific interval of time, but also movement information was obtained. Performance of a motoric task can be assessed by either the outcome of the performance or the production of the performance (Spirduso, Francis, & MacRae, 1995). In our case, the outcome of the performance was the score for each of the Purdue Pegboard tasks derived from the number of correctly placed units. The production of the performance was assessed by certain movement measures that quantified the movements.

The use of kinematics in the present study derived several movement measures from which we selected only two of them: "*angular displacement*" and "*angular velocities*". The reason for selecting these parameters is that the finger and hand movements required in the Purdue Pegboard are very varied and a complex analysis appraising all movements was out of the scope of this study. Thus, fingers are performing the fine movements we are interested in and this execution demands more attentional control. The fingers converge toward a point in the wrist joint area when they are flexed. Then, a determined angle between the fingers most used in this task (i.e., thumb and index) will give substantial movement information.

The angle was in fact determined between the middle of the thumb, the basis of the thumb and the middle of the index finger. It is important to clarify that in spite that four markers were placed on the subject's hands we employed only three of them. Future studies will employ the rest of the collected data. In the present study, the angle was tracked to obtain information about how the angle moved or got displaced. Displacement describes how the hand moves through space and time (Stergiou & Decker, 2011). So, angular displacement gave us information about how much or how little the angle rotates (Spirduso et al., 1995). Velocity on the other hand, is the rate of change in position over the change in time (Spirduso et al., 1995). Hence, angular velocities gave us information about the velocity of the angle from picture to picture, that is, how fast the angle moves in a direction while the participants performed the task.

For each of the kinematic measures three descriptors were used: the Mean, which summarizes in average displacement movements, the Standard Deviation which is a measure of dispersion and shows variations around the mean, and the Coefficient of Variation (COV), which is an index of variation expressed in percentage. We want to underline that special stress is made on movement variability because the selected tasks require repetitive movements. Moreover, cumulated data in the field of movement research indicate that variability is a central issue in motor control that may indicate high adaptability and in some cases pathology (Stergiou & Decker, 2011). Increased variability within movements in elders compared to younger adults have been well-documented in the literature (C. J. Ketcham & Stelmach, 2001). Cooke et al. (1989) derived from kinematic analyses the finding that elderly subjects had greater coefficients of variation in arm movements than did younger subjects. Brown (1996) found that elderly subjects in comparison to younger subjects had greater trajectory variability in single-joint arm movements. Therefore, we determined the **amount** of movement variation with these three descriptors.

Aims and hypotheses.

The present study has two main goals. First, we wish to evaluate age-related differences on kinematic measurements during performance of the Purdue Pegboard test. At this respect we hypothesize that a) older adults will show slower performance and more variability in finger movements as compared to young participants. The second objective is to assess whether executive functions and attention would be significantly associated to performance in dexterity tasks in healthy elderly subjects. For this goal, we hypothesize that b) significant associations between cognitive performance and dexterity outcomes will be observed on the elderly group, particularly on the assembly task since this is the most demanding condition. In addition, we expect to find differences between groups for cognitive performance.

Method

Subjects

Thirty healthy, right-handed individuals, divided into two age groups participated in the study. The young group consisted of 15 young adults (9 females, 6 males; age *M* = 26.07 years, *SD* = 3.43) and the elderly group consisted of 15 healthy elderly over 67 years of age (10 females, 5 males; age *M* = 74 years, *SD* = 6.88). Number of male and female subjects on each group was almost equivalent, however, there were more females (19) than males (11) in both groups.

Recruitment of the participants was as follows: The elderly sample was mainly recruited from a local senior citizens center (Heracleum). A poster was used to announce the research study and inform potential participants of its requirements. In this way, many seniors contacted us and they were enrolled in the study. Also, we recruited elderly persons in a so-called “snowball effect“. Meaning by this that we asked each participant, before they left the laboratory, to take written information with them and bring it to their acquaintances. Thus, some participants were also recruited through the first enrolled subjects. Concerning the young group, we basically recruited students from around campus at The University of Tromsø, where the study took place.

At the initial part of the study, participants received once more information about the research project including the possibility to withdraw from the project at any given time. All participants signed an informed consent before the study was undertaken. During an interview, information about the participants' gender, age, level of education, smoking habits and fitness was gathered. Health conditions such as hearing, sight, and current and previous health status were self-rated by the participants and registered by the experimenter. None of the participants was taking medication known to affect the central nervous system, had suffered any stroke or head trauma, or had any other health problems which could interfere with performance in this study.

Participants in both groups were screened for depression and dementia in order to assure inclusion of healthy participants. Screening for depression was executed with the Beck Depression Inventory (BDI) (Beck, Steer, & Carbin, 1988). This is a self-report of depressive symptoms where a score < 10 shows none or minimal depression; a score within the range of 10 - 18 displays mild to moderate depression; a score within the range of 19 - 29 is considered moderate to severe depression; and a score > 30 displays severe depression (Beck et al., 1988). It is important to screen for depression as mood disturbances are known to affect performance on cognitive tasks (Cohen, Weingartner, Smallberg, Pickar, & Murphy, 1982). None of the participants in the young group scored within the depressed ranges, whereas 3 of the older participants scored above 11. However, these participants were not excluded from the study as the BDI contains questions regarding loss of appetite and sleep disturbance, which are complaints much common to the elderly population (Beck et al., 1988). To screen for incipient demented persons the Mini Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975) was carried out. This is a widely employed 11-item instrument used to assess the general cognitive state of a person. It measures five cognitive domains: registration, orientation, attention, recall and language. Scores range from 0 to 30 and the cutoff of 24 was used to exclude individuals with a possible dementia state. None of the participants scored below 25, and thus, none were excluded from the study.

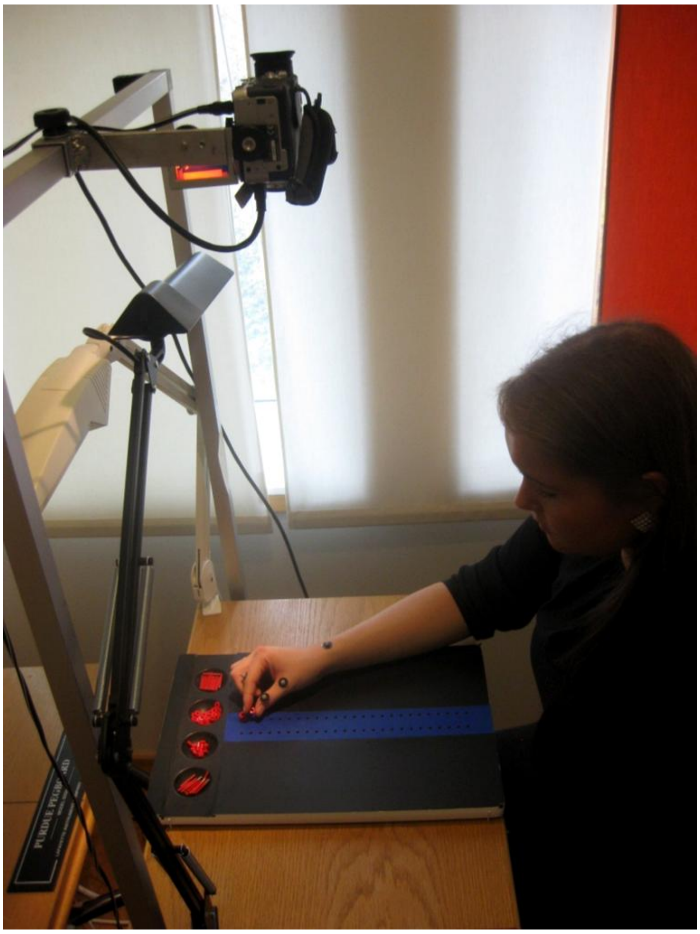
Material for movement analysis

Vicon Motus System (Vicon Motion Systems, Inc). This is a motion capture system based on the use of reflective markers, a video camera, a PC and a software for automatic video tracking and movement analysis.

Reflective markers. Four reflective markers of 6.4 mm were attached to the participants’ right hand prior to video recording

Sony Handcam DCR-PC100E. For video recording a Sony Handcam DCR-PC100E was used. The camera was properly fastened on a rack placed above the pegboard desk to ensure that every trial was recorded from the exact and same viewpoint (see Picture 1). The position of the camera was top-down, hence the reflective markers on the participants' hand were filmed from a dorsal view.

Picture 1



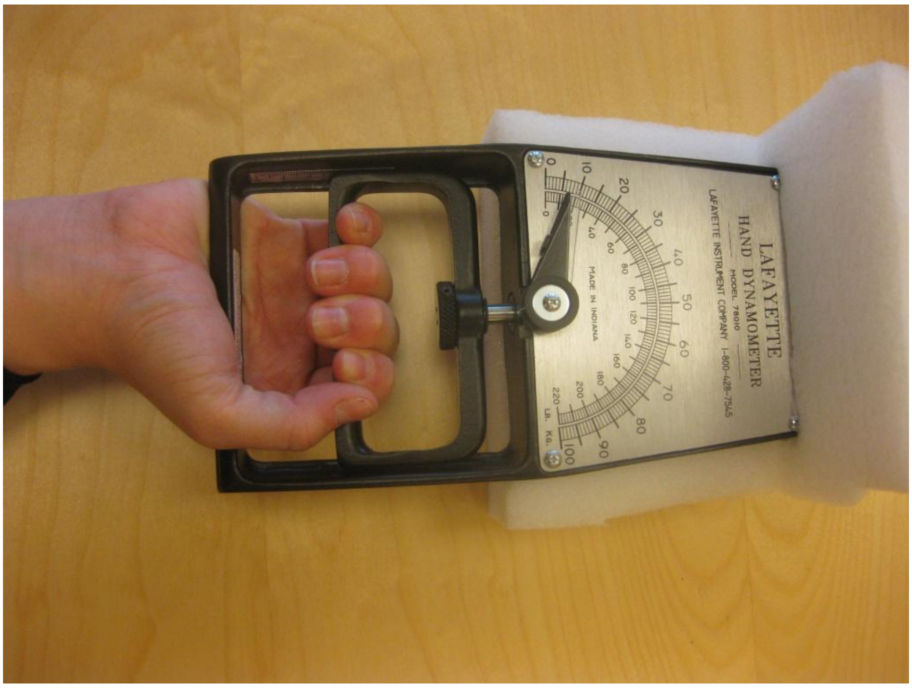
Material for neuropsychological assessment

A battery comprising 7 neuropsychological tests was applied to all subjects. Here follows a description of each task.

Digits Span Forwards and Backwards are two related subtests from the WAIS-R (Wechsler, 1981). Both tests are widely used in neuropsychological research to examine short-term memory and working memory capacity respectively. The tests consist of reading aloud strings of digits to the subject, starting with only simple series of numbers and increasing on each trial the number of items. The participants' task is to repeat the digits either in the right order after hearing them (Digits Span Forwards), or in the inverse sense (Digits Span Backwards). The number of digits increases by one for each string of digits, and one point is given for every correctly repeated series.

The Hand Dynamometer 78010 (Lafayette Instrument Company, 2012). This device was used to measure hand strength (Picture 2) and is part of the Halstead-Reitan battery (Lezak, 1995). Because the participants were to use only their right hand for the dexterity task in this study, only the right hand strength was measured. Before the trials, the handle was adjusted for the size of each participant. The experimenter illustrated how to use the dynamometer prior to the trials. The participants were told to use maximum force when squeezing the handle. Three trials were given for each hand, with a 15 second pause given between each trial. A mean for the three trials was calculated and set as the final score.

Picture 2



*The Handedness Inventory (*Briggs & Nebes, 1975) is a revised version of Annett's hand preference questionnaire and was used to measure strength of laterality of a person's right or left hand use in everyday activities. It is a five-point scale where one choose between "always" responses which gives two points, "usually" responses which gives one point, and "no preference" responses which gives zero points. Preferences for the left hand are scored negative whereas preferences for the right hand were scored positive, so that the minimum score of this test would be -24 and +24 would be the maximum score. A score of +9 and above is considered right-handed, a score ranging from -9 to +8 is considered mixed-handed, and scores from -9 and below is left handed. All the participants came out as right-handed according to this questionnaire.

The Purdue Pegboard (Tiffin & Asher, 1948) was originally used for selection of industrial personnel in the 1940's as a test of dexterity. However, since then, it has been widely employed in neuropsychological assessment, such as in the present study, as a measure of fine manual dexterity. The test is performed on a board with two parallel rows with 25 holes in each. Four cups at the upper end of the board are filled with pins, collars and washers respectively, sorted separately. Because the Purdue Pegboard is the primary task of the present study, further details of the specific method employed with this instrument will be stated on the “ Dexterity Task” section (see page 26).

The Stroop Test (Golden, 1978) is a well-known test that involves inhibitory processes and attentional mechanisms, measures of selective attention. The test is comprised of three subtests. Part one (Stroop Word) is printed in black ink where the words *blue*, *red* and *green*, listed in random order, is to be read as fast as possible in 45 seconds. In part two (Stroop Color) the word *XXXX* is printed in either blue, red or green ink in random order, and the participants are supposed to designate the color of the word as many times as possible within 45 seconds. Part three (Stroop Color and Word) is comprised of the words *blue*, *red* and *green* listed in random order. However, the color of the words do not match the words themselves (e.g. the word *blue* is written in red ink), and the participant is to read the color of the word as fast as possible within 45 seconds. Time was controlled with a digital stopwatch. All three subtests give a score based on the number of correct words read aloud. The Norwegian translation was used for the present study.

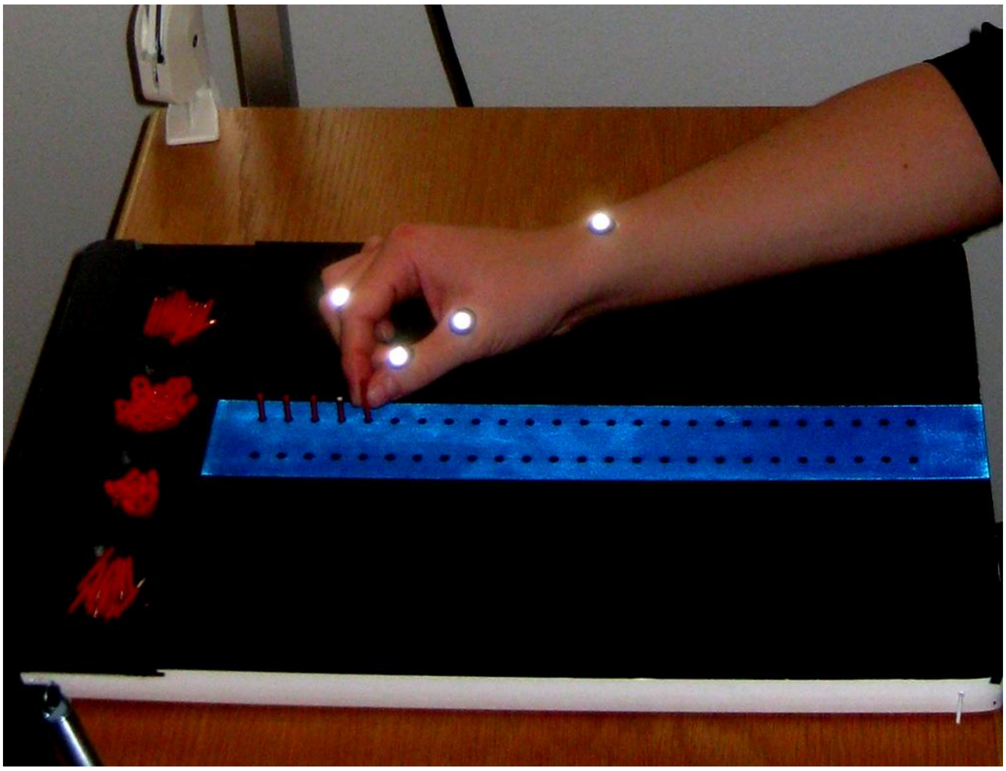
The Trail Making Test (TMT) is a highly popular neuropsychological test providing insight in the subject’s speed of processing, visual search and executive functions (Tombaugh, 2004), and is a part of the Halstead-Reitan Battery (Reitan & Wolfson, 1985). In part A of the test the participant is required to draw connected lines as fast as possible to encircled numbers, starting with 1 and ending with 25, in ascending order. The encircled numbers are randomly placed on a sheet of paper. Part B is comprised of both numbers and letters placed randomly on a sheet of paper. Here the participants have to draw connected lines alternating between numbers and letters, starting with a number and then followed by a letter, always connecting in an ascending order. For example, correct performance on this task will start from 1 to A, then from A to 2, and from 2 to B, and so on. The amount of time required on each part gives the score for each test.

Dexterity task

As previously mentioned, we employed two of the Purdue Pegboard tasks (Tiffin & Asher, 1948) to evaluate dexterity of the right hand. Namely, we used "the inserting pin task" and "the assembly task". In the former test, the participant had 15 seconds to insert as fast and as many pins as possible into the pegboard holes. The pins were to be placed one by one into the right row of holes. The number of pins inserted within the 15 seconds time-limit was registered as the score for this subtest. In the assembly test, the participant was given 45 seconds to perform the task. This time, the participant was required to assemble the different pieces presented in cups at the top of the pegboard (i.e., pins, collars and washers). Subjects were instructed to make assemblies by using the holes on the right row. An assembly was built by first putting a pin into the hole, then a washer, then a collar and finally another washer. Each time, subjects were required to execute the assembly in the same order and as fast as possible. The total number of single units assembled within 45 seconds was the score for this subtest. The time given on each test was automatically timed by a preset recording duration in the Vicon Motus system.

Furthermore, the color of the pegboard (originally in white) and the manipulated material (originally in chrome) had to be changed in order to obtain a sharp contrast between the reflective markers and the background. For the recording of both subtests we employed a Sony Handcam DCR-PC100E camera that was managed by the Vicon Motus software and which required a good contrast to obtain good quality images for processing. Thus, the board was painted in black, the row section with the holes were painted dark blue, and the rest of the material (pins, collars and washers) in red. The reason to paint assembly material in red was that the pieces were originally so shiny that they were often confounded by the motion software as the reflective markers (see picture 3). We had to use three different colors to ensure that the participants had no trouble differentiate between the components.

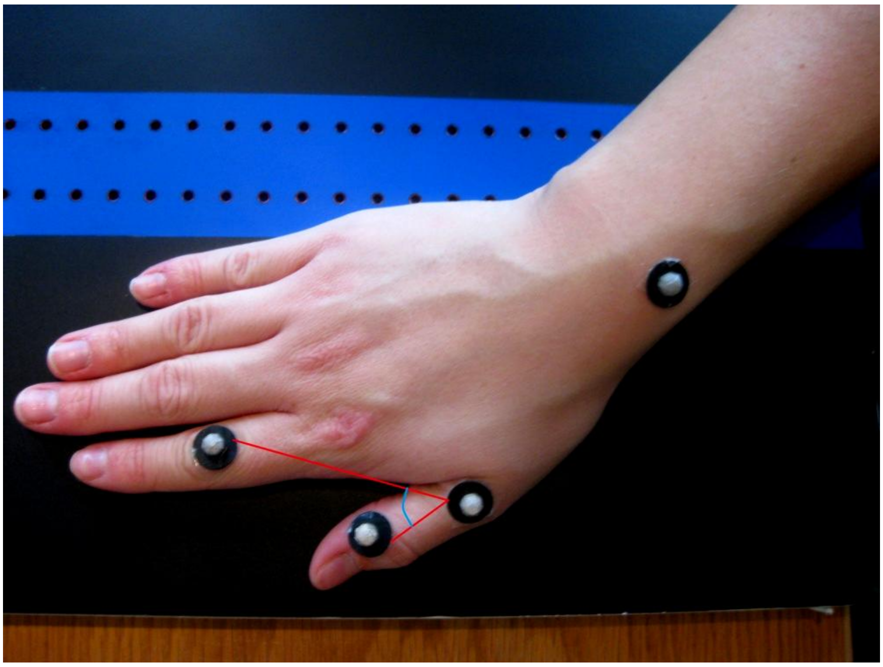
Picture 3



Procedure

Motion Capture. Prior to the task the reflective markers were placed on the dorsal view of the right hand on the following anatomical landmarks: point (1) processus styloideus radii, point (2) basis of phalanx proximalis pollicis , point (3) basis of phalanx distalis pollicis, point (4) articulatio interphalangealis proximalis II (Schuenke, Schulte, & Schumacher, 2010) (see Picture 4).

Picture 4

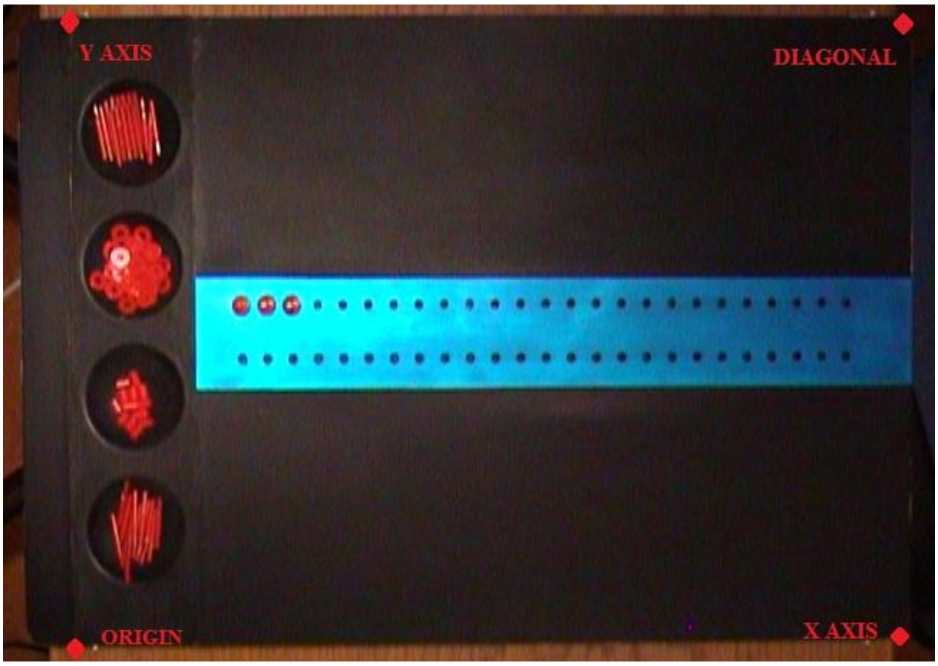


The experimenter checked with the subjects to make sure that they felt the markers fitted comfortably on their hand. The experimenter demonstrated the task for the participant at the very beginning, and asked if the participant had clearly understood the task. All subjects were given enough time to practice before each task. Prior to starting the task and video recording, the participants were told to rest their hand at the board with the palm facing down, at the right side of the Pegboard. This assured that all participants had the same starting point for the video recordings. Participants were told to start the task as soon as they heard the command "*start*" from the experimenter, and to stop as soon as they heard the command "*stop*". The participants were all asked to complete as many units as possible within the given time frame.

Before each testing session, the light setting in the lab was checked. At every trial we made sure that only a dimmed light in the ceiling was on and that all shades in front of every window were shut down to minimize interfering light sources. Throughout the whole period of recording trials, the lighting system in the lab remained at the same intensity to ensure a minimum of variation between trial recordings.

Video recording. The automatic camera light was left on to maximize the reflection from the reflective markers. As previously mentioned, the video camera was connected to the Vicon Motus software, which directed the video recording. A template made in advance was used to identify the anatomical points equivalent to the fixed markers on the subject's hand. The camera was activated together with the software to start recording. Then, calibration of the video system recording took place by identification of four definite points, *Origin*, *X Axis*, *Diagonal* and *Y Axis* (see Picture 5).

Picture 5



Duration of video recording followed time limitations of each subtest, the *minimum duration* was 15 seconds for the inserting pins task and 45 seconds for the assembly task. A *delay* for video recording of 4 seconds was enabled. Additionally, a beep signal indicating the start of the recording was activated. This procedure assured that all hand motion was properly recorded starting always with an image of the subject’s hand at rest on top of the pegboard. To start the recording, *record* was activated.

Post-processing of digitized points. After the testing session, a post-processing of the video recordings took place. This part of data treatment was, to some extent, necessary to check for possible missing points (i.e., markers disappearing in some video images) or other various conditions that hinder correct and automatic data analysis. For example, a few of the trials were recorded on some particularly sunny days where extra light came through the shades and on these particular trials the reflective markers were not registered by the camera and/or the software as it was in other trials. For these circumstances small adjustments with brightness were made. Additionally, it is worth mentioning that post-processing of data is always necessary for the attainment of motion parameters.

Mostly, tracking of markers on the recorded videos was made automatically by the Vicon Motus software. Nevertheless, sometimes manual tracking was necessary such as when points were missing from the images for a period of time, or when two or more points were too close to each other that discrimination of both points could not be distinguished due to blurry images. The reason for some of these irregularities is that for instance, every hand is slightly different in shape and size. Then, the template made in advance could only fit all different hands to a certain extent. For example, some subjects had smaller hands and some points came closer on the hands of these subjects which made automatic tracking of designated points a challenge. In these cases, small adjustments with the software's search width and/or search height for the points were made. In the cases when a point went missing from some images, the particular point was registered as "*missing"* and put back on when it reappeared.

Data processing. The data material from the recordings had to be extracted from the Vicon Motus software in order to execute further data analysis in Excel and SPSS. In order to do so, data from the recordings had to be processed in the Vicon Motus software in advance. To this end we filtered all the recordings by using a cutoff frequency of 10 (Hz). This was all done with one trial at a time, and thereafter we could obtain the data of interest which were angular displacement and angular velocities.

The processing of the recorded material, digitizing of points and extracting of data was used consequently across all trials in the study.

General procedure. The study took place in a quiet laboratory at the University of Tromsø. Duration of the experiments was approximately 45 minutes for the young participants and 75 minutes for the elderly. The difference in testing time between young and older adults was mostly due to the fact that administering and explaining the different tests was more time consuming with the elders. Also, elderly participants often had a small coffee break before testing and in between the cognitive testing and the dexterity tasks to avoid fatigue. An initial interview was undertaken to get demographic data. Subsequently, the cognitive test battery was administered starting with the MMSE and then the Digits Span Forwards and Backwards. Then, the Hand Dynamometer was carried out in order to give the participants a little break in the cognitively challenging tasks. Thereafter, the TMT, the Stroop test, the Handedness Inventory and the BDI were administered in that order. Finally, the participants were led to a side room in the laboratory where the video recording of the dexterity tasks were performed. Once the participants got reflective markers attached to their hands the dexterity tasks were carried out. At completion, the participants received a lottery ticket valued 20 NOK. Processing of data was done at a later time by the experimenter.

Statistical Analysis

Angular displacement and angular velocities were calculated and extracted from kinematic analyses in the Vicon Motus software. The particular angle measured by angular displacement and angular velocities can be seen in Picture 4. Further analyses were carried out with IBM SPSS Statistics 20 and Microsoft Office Excel 2007. Independent-t-tests were conducted to compare results for the young and the elderly groups regarding the cognitive tests and the demographic variables.

Concerning results on the Purdue Pegboard different statistical analyses were employed to analyse the various outcomes. For each kinematic variable three main descriptors of movement were calculated: the Mean (M), the Standard Deviation (SD) and the Coefficient of Variation (COV). Both parametric and non-parametric analyses had to be employed to evaluate differences between groups and across conditions on the three descriptors. Detailed information about the specific statistical analyses is given in the Results section.

Results

Demographics and background variables

Table 1 presents statistics for the demographics and background variables. Groups were comprised of slightly more females (n= 19) than males (n= 11). Formal education for the young group was *M* = 16.37 years, *SD* = 1.49, and *M* = 13.03, *SD* = 3.88 for the elderly group. In terms of years of education the groups differed significantly, probably due to improvement of the educational system in Norway during the last few decades. Groups also differed significantly on MMSE performance, but not on performance of the BDI.

Table 1

Demographics and background variables by age group

	Young (n = 15)		Elder (n = 15)		*t* (28)	*P*
F/M Ratio	9/6		10/5			
	M	*(SD)*	*M*	*(SD)*		
Age	26.07	3.43	74.00	6.88		
Years of education	16.37	1.49	13.03	3.88	3.12	0.004**
MMSE	29.47	0.64	28.13	1.60	3.00	0.006**
BDI	3.13	2.90	5.47	3.54	-1.97	0.058

Note. **p<.01

Neuropsychological test battery

Results for the cognitive test battery are summarized in Table 2. Significant results were obtained on most of the employed tests. The strongest significant differences, (p <.001) were observed on part A and B of the TMT in which elders displayed longer times than the younger group, this was also true for the Stroop subtest Word and the Purdue Pegboard tests. Afterwards there were observed significant differences (p < .01) on the Color part of the Stroop test, grip strength and the Handedness Inventory. Concerning the latter test, it is important to remark that there were obtained higher scores for the elders. Interestingly, results obtained from the Digits Forwards, $t(28) = 0.48$, $p = .634$, and Digits Backwards, $t(28) = 1.72$, $p = .097$, did not turn out to be significant, nor did the Stroop Word subtest show significant group differences. Regarding the principal tasks of the present study, the Purdue Pegboard tasks, it is important to underline that the elderly performed, not unexpectedly, worse than young adults. The groups differed significantly in both the inserting pins task and the assembly task. However, it is important to remark that results reported in this section relates to the overall performance expressed in Mean and SD for the 15 and 45 seconds allotted on the inserting pins task and the assembly task respectively. A more detailed analysis of the Purdue Pegboard task together with movement analyses on the same test will be presented under "Dexterity Tasks".

Table 2

Means and standard deviations for Digits Backwards, Digits Forwards, Stroop Test, Trail Making Test, Purdue Pegboard, Hand Dynamometer and Handedness Inventory by age group

	Young		Elder		T	
	M	*(SD)*	*M*	*(SD)*	(*df* 28)	*p*
Digits Span						
Digits Forwards	7.93	1.91	7.60	1.88	0.48	.634
Digits Backwards	6.67	1.88	5.60	1.50	1.72	.097
Stroop Test						
Word	101.53	9.35	94.93	10.57	1.81	.081
Color	73.07	5.75	62.40	10.62	3.42	.002**
Word and Color	46.53	7.51	31.00	6.59	6.02	**.001*** **
Trail Making Test						
Test A	19.77	6.29	39.70	9.99	-6.54	**.001*** **
Test B	44.37	8.50	102.20	28.54	-7.52	**.001*** **
Purdue Pegboard						
Inserting pins task	9.60	1.12	6.07	1.03	8.98	**.001*** **
Assembly task	27.40	1.55	17.00	2.42	14.02	**.001*** **
Hand Dynamometer	40.98	12.14	28.44	9.66	3.13	.004**
Handedness	19.33	3.02	22.27	2.69	-2.81	.009**

Note. **p<.01 are reported with underlining, ***p<.001 are reported in bold.

Dexterity tasks

To obtain fine behavioral and kinematic analyses of performance on the Purdue Pegboard tasks, each task was analyzed by periods of time. On the easiest task, namely the inserting pins task, we decided to create two periods of 7.5 seconds each. In this way we compared initial performance versus final performance. For these analyses we employed a two-way mixed ANOVA to examine any possible differences regarding the number of inserted pins between intervals or groups. Results did not reveal a main effect for interval, *F*(1,28) = 3.11, *p* = NS, nor an interaction between group and interval. However, there was a significant difference between groups on the number of inserted pins by period of time, *F*(1,28) = 57.57, *p* < .001. Figure 1 shows these results. Both the elderly group and the young group had an increase in number of pins inserted from the 1st to the 2nd interval. However, the young group inserted significantly more pins than the elderly group across both intervals.

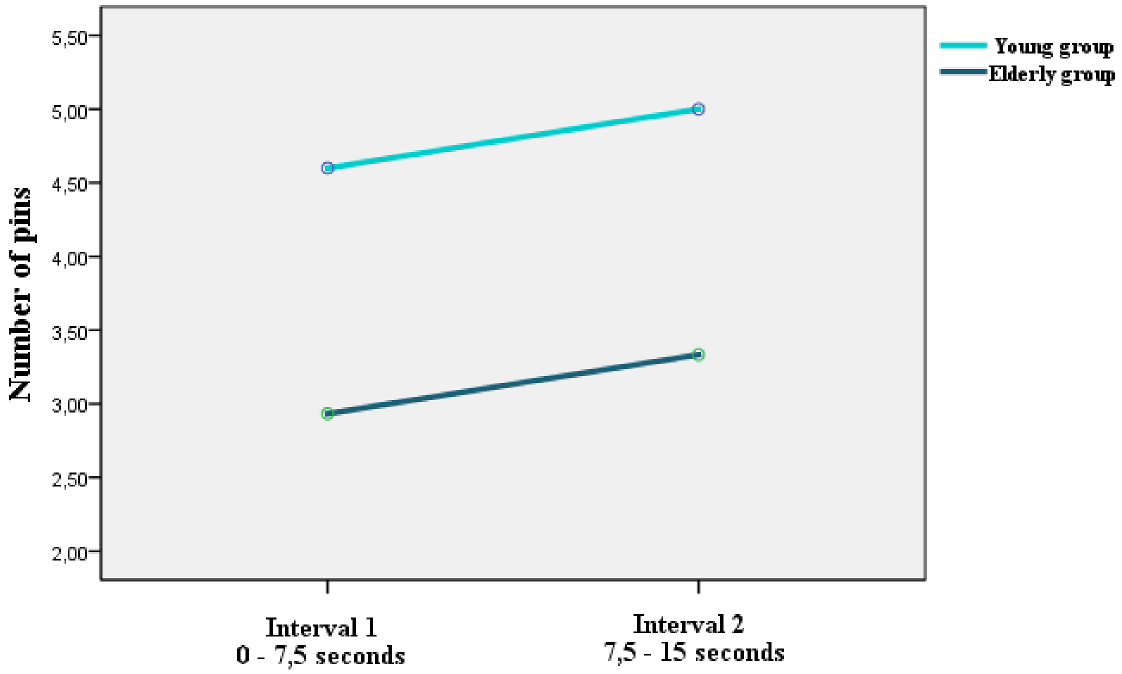


Figure 1. Number of pins inserted per age group by intervals.

Figure 2 displays the results from the assembly task, which run for 45 seconds. This task was divided into three intervals; interval 1 goes from 0-15 seconds; interval 2 goes from 15-30 seconds; interval 3 goes from 30-45 seconds. In this pegboard task, results from a two-way mixed ANOVA showed again no main effect for intervals, *F*(2,56) = 0.1, *p* = NS, and no interaction, *F*(2,56) = 1.4, *p* = NS. Though, once more a between groups difference was detected. The young group significantly outperformed the elderly in terms of number of units inserted at all intervals, *F*(1,28) = 196.48, *p* < .001. The elderly group seemed to have a slight drop in number of inserted units at the 2nd interval whereas the young group stayed constant. At the 3rd interval the young group seemed to insert slightly less units and the elderly group increased the number of inserted units.

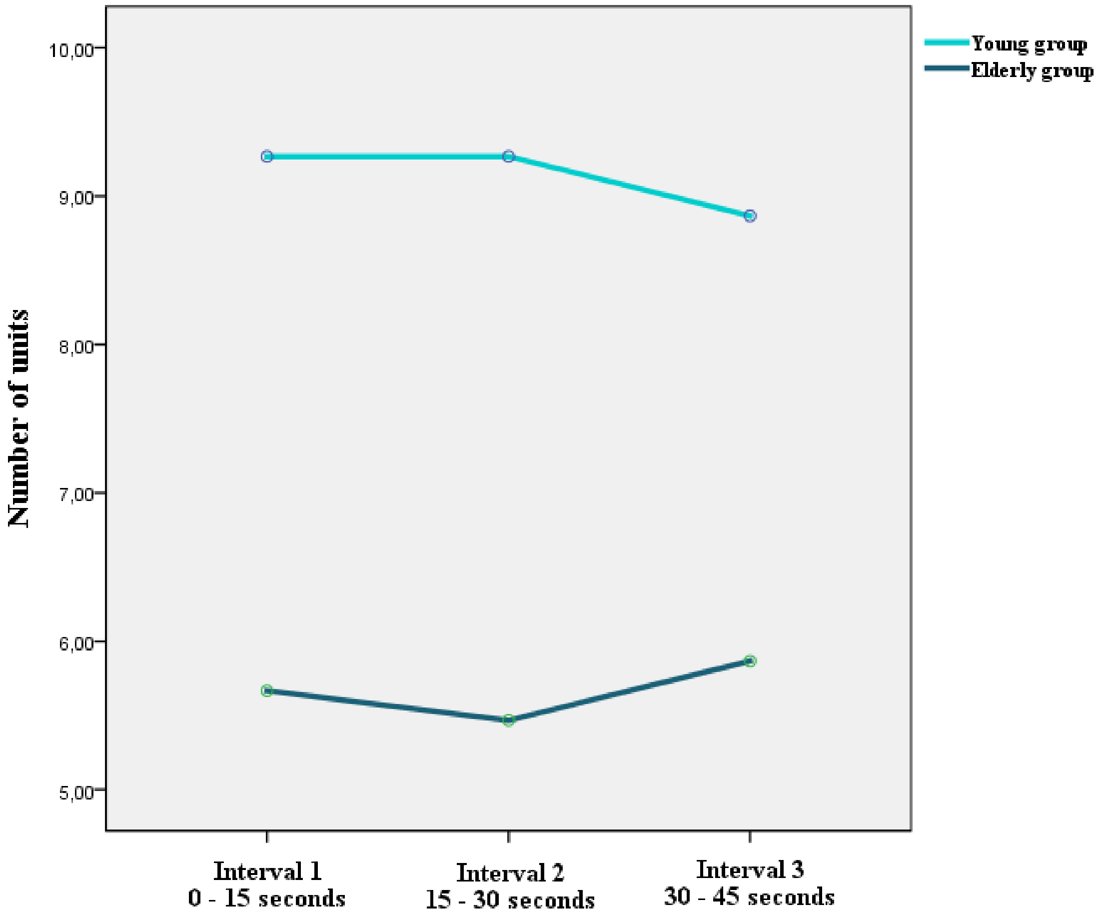


Figure 2. Number of units (pins, collars and washers) inserted per age group by intervals.

Movement analysis of dexterity

For movement analysis two types of measurements were obtained, angular displacement and angular velocities. Angular displacement gives us information about how much the given angle on the participant's hands (see Picture 4), rotates in the dexterity tasks. Angular velocities gives us information about the rate at which the position of the angle changes. These parameters were calculated for the inserting pins task as well as for the assembly task. Following the same rationale than for the analyses of number of pins and units inserted and due to huge amount of generated data, we analyzed each task by the same periods of times previously described. As before, the inserting pins task was divided in two parts of 7.5 seconds each, while the assembly task was divided into 3 intervals of 15 seconds each (i.e., 15sec, 30 sec and 45 sec). Thereafter, Coefficient of Variation (COV), Standard Deviations (SD) and Mean were calculated for all intervals of each task. Statistical analyses were then carried out across intervals and groups.

Results for the inserting pins task.

To begin with, we evaluated the normality of data by using the Shapiro Wilk test, which showed significant results for all tested variables. For this reason, we proceeded to apply non-parametric statistics. For assessment of between group differences, the Mann-Whitney test was employed, while the Wilcoxon signed rank test was used to evaluate differences between intervals by age group. Overall results showed no significant differences in any of the movement measures (i.e., angular displacement, angular velocities) across groups or across intervals.

Results for the assembly task.

For this task three time intervals were obtained with their respective set of descriptors. In the same way as with the prior task, we performed analyses of normality on all data by time interval. Again, most of the variables did not accomplish normality assumptions and therefore, non-parametric tests were applied. However, a few variables showed normal distribution and for them parametric tests were employed. Due to the large number of statistical analyses carried out, it will only be referred in the following section to those analyses showing significant results.

Angular displacement. For this characteristic of movement, we utilized the Mann-

Whitney test since variables were not normally distributed. Results showed only significant differences between age groups for the COV of last interval (45 sec) (U = 65, $p < 0.05$). See Figure 3.

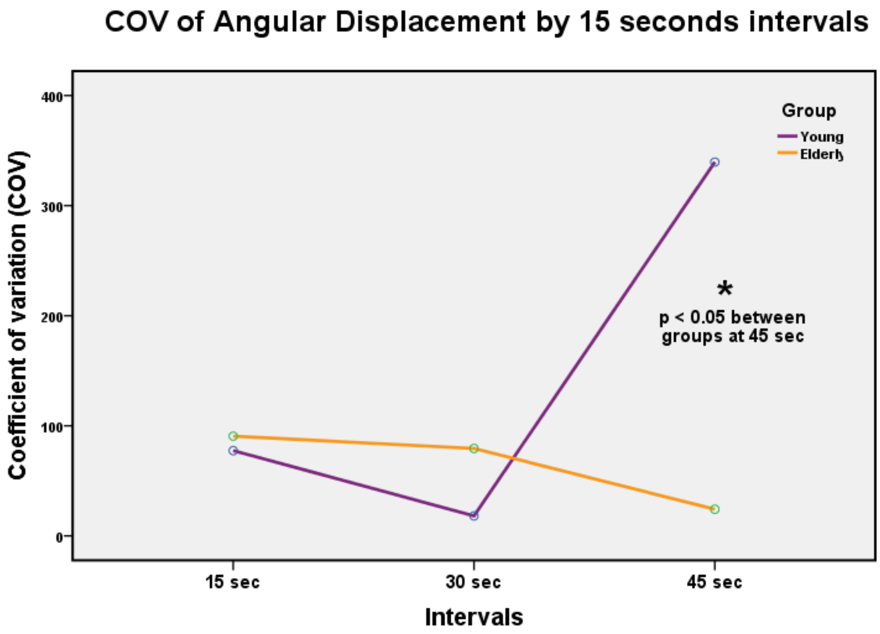


Figure 3. COV angular displacements by intervals.

Angular velocities. Analyses of between group comparisons were again performed with the Mann-Whitney test. This time the Mean of angular velocities differed significantly between both groups on the 2nd interval (i.e., 30 sec). Furthermore, a Friedman test revealed that only the elderly adults performed significantly differently across trials. In fact, the older group seemed to decrease movement in terms of number of degrees per second at the end of the task. See Figure 4.

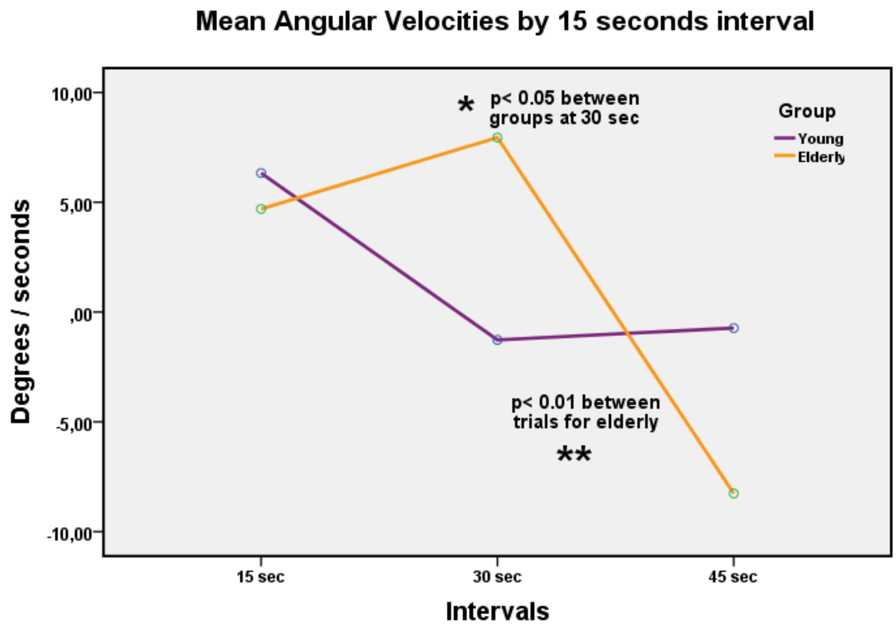


Figure 4. Means angular velocities by intervals.

Finally, significant differences were observed between trials on the SD of angular velocities. Because the distribution on this specific variable actually met assumptions for normality and sphericity, we performed a 2-way mixed model analysis of variance (ANOVA). This test allowed for comparisons across groups and trials. The results showed clear significant differences across trials (*F (2, 56)* = 5.80, p < 0.01), but not a significant interaction effect (*F (2, 56)* = 0.5, p = NS). Finally, the analysis did not show any significant difference between groups (*F (1, 28)* = 2.94, p = NS). Figure 5 illustrates these results.

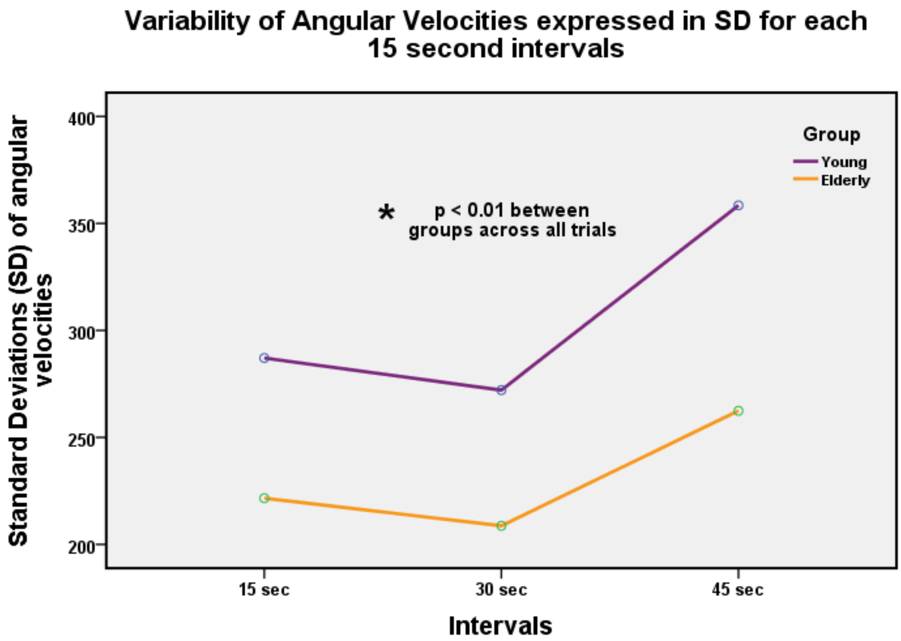


Figure 5. Variability measured by standard deviations (SD) in angular velocities by intervals.

Correlational analyses between dexterity kinematic data and cognitive performance

Bivariate Person's *r* correlations were employed to evaluate the association between Mean, SD and COV for the motion parameters - for all time intervals - and the cognitive tests. Correlations were calculated for both groups together, and then stratified analyses for each age group (i.e., young group separately and the elderly group separately).

The inserting pins task.

The results for the correlations of the inserting pins task are displayed in Table 3. Note that two types of associations are reported on this Table: 1) correlations between angular displacement and cognitive tasks (upper part) and 2) correlations between angular velocities and cognitive tasks (lower part). Additionally, results are shown for the whole sample, the elderly group separately and the young group separately.

Correlations for both groups. These analyses showed few significant correlations specifically on angular displacement in the 1st interval. The index of variability COV was the highest correlated with MMSE, $r = .61$, $p < .01$. The rest of the significant correlations displayed similar values for COV and TMT A, $r = -.37$, $p < .05$, and for Mean of angular displacement and MMSE, $r = .37$, $p < .05$. The only significant associations obtained for angular velocities were between Mean and MMSE on the 1st interval, $r = .40$, $p < .05$, and between COV and Hand Dynamometer (grip strength). This latter correlation turned out to be a negative one, $r = -.53$, $p < .01$, maybe due just to a difference in male and female hand strength.

Elderly group. Correlations performed separately on the elderly group showed various strong associations for both angular displacements and velocities. Regarding angular displacement in the 1st interval, moderate to strong significant correlations were found between the MMSE and two of the kinematic descriptors: the Mean, $r = .54$, $p < .05$, and the COV, $r = .67$, $p < .01$. Also, it is important to observe that two strong correlations were obtained between the Mean of angular displacement and Digits Span Backwards on the 1st, $r = .72$, $p < .01$, and 2nd interval, $r = .69$, $p < .01$. This was also found for Digits Span Backwards and the Mean of angular velocities, $r = .74$, $p <.01$. Finally on the 1st interval only one more correlation was obtained between SD of angular displacement and Stroop Word, $r = .52$, $p < .05$.

As for the 2nd interval, we got four significant correlations aside of the strong one already mentioned between Mean and Digits Span Backwards. These four values were similar in degree of association. Two of them were found between the Mean of angular velocities and MMSE, $r = .57$, $p < .05$, and the Mean of angular velocities and Digits Span Forwards, $r = .52$, $p < .05$. Interestingly, the two last correlations were also obtained for the SD of angular velocities and Digits Span Forwards on the 1st, $r = .54$, $p < .05$, and 2nd intervals, $r = .54$, $p < .05$.

Young group. Similar to the correlations obtained for both groups, correlations for the young group displayed few significant associations in the 1st interval, the only two being for

COV of angular velocities and TMT A, $r = .60$, $p < .05$, and Stroop Word and Color, $r = -.55$, $p < .05$. The only significant correlation found with angular displacement were that of COV and TMT B in the 2nd interval, $r = -.57$, $p < .05$. As for angular velocities, we got five significant correlations in the 2nd interval, one of them being with COV and TMT A, $r = -.66$, $p < .01$, quite alike results on the 1st interval. The young group separately, just like both groups, also showed a significant negative correlation with COV and Hand Dynamometer, $r = -.58$, $p < .05$. A significant negative association with COV and age was also found, $r = -.57$, $p < .05$. The last two correlations were found between Mean and Stroop Word, $r = .60$, $p < .05$, and SD and Digits Span Backwards, $r = -.55$, $p < .05$.

The assembly task.

The results for the correlations of the assembly task are shown in Table 4. In this Table, the reported associations are: 1) correlations between angular displacement and cognitive tasks (upper part) and 2) correlations between angular velocities and cognitive tasks (lower part). The angular displacement and angular velocities are divided into three time intervals, and are shown for the whole sample, the elderly group separately and the young group separately.

Correlations for both groups. Correlations for both groups showed very little significant associations with angular displacement, with only one significant correlation for COV and Hand Dynamometer in the 3rd interval, $r = .43$, $p < .05$. Regarding angular velocities, significant associations were only found in the 3rd interval: COV correlated significantly with both Digits Span Forwards, $r = -.57$, $p < .01$, and Digits Span Backwards $r = -.47$, $p < .01$. Also the Stroop test correlated significantly with Mean and subtest Word, $r = .53$, $p < .01$, and SD and subtest Word and Color, $r = .39$, $p < .05$.

Elderly group. These analyses showed several significant associations with angular displacement mainly in the 1st interval, whereas only three significant correlations were found with angular velocities.

Angular displacement. For this dexterity parameter, the only significant association on the 2nd interval was between COV and TMT A, $r = -.52$, $p < .05$. As mentioned above, no correlation was found in the 3rd interval. For the 1st interval the following correlations turned out to be significant: SD correlated significantly positive with age, $r = .61$, $p < .05$, and TMT A, $r = .60$, $p < .05$, and negative with MMSE, $r = -.53$, $p < .05$, and Hand Dynamometer, $r = -.56$, $p < .05$. Mean in the 1st interval also showed significant associations with age, $r = .64$, $p < .01$, and TMT A, $r = .70$, $p < .01$, which were positive associations, whereas correlations with MMSE, $r = -.70$, $p < .01$, and Hand Dynamometer, $r = -.55$, $p < .05$, were negative.

Angular velocities. The only significant correlations found for angular velocities were Mean in the 1st interval and TMT A, $r = .53$, $p < .05$, Mean in the 2nd interval and age, $r = -.61$, $p < .05$, and lastly SD in the 3rd interval and Stroop Word and Color, $r = .60$, $p < .05$.

Young group. Correlations for the young group separately showed no significant correlations for SD and cognitive tests in the assembly task.

Angular displacement. Mean correlated significantly only with TMT A in the 1st interval, $r = .53$, $p < .05$. The index of variability COV was the highest correlated with TMT A, $r = .74$, $p < .01$. As for the rest of the significant associations, similar values were displayed for COV and Stroop Word and Color in the 2nd interval, $r = .58$, $p < .05$, and for COV and age in the 3rd interval, $r = .55$, $p < .05$.

Angular velocities. As for angular velocities we only found significant associations in the 3rd interval. Mean correlated significantly with Stroop Word, $r = .69$, $p < .01$, whereas COV correlated significantly with both subtests of Digits Span; Forwards, $r = -.72$, $p < .01$, and Backwards, $r = -.70$, $p < .01$. All of these correlations of angular velocities were in line with the ones from both groups together.

Table 3.

Significant correlations for Mean, SD and COV for Angular Displacement and Angular Velocities in the inserting pins task and cognitive tests

	Both groups			Old group			Young group		
	M	**SD**	**COV**	**M**	**SD**	**COV**	**M**	**SD**	**COV**
Ang. Displacement									
1st interval									
MMSE			.61**	.54*		.67**			
TMT A			-.37*						
Stroop Word					.52*				
Digits Span Backwards				.72**					
2nd interval									
MMSE	.37*								
Digits Span Backwards				.69**					
TMT B									-.57*
Ang. Velocities									
1st interval									
MMSE	.40*			.57*					
TMT A									.60*
Stroop Word and Color									-.55*
Digits Span Forwards				.52*	.54*				
Digits Span Backwards				.74**					
2nd interval									
Age									-.57*
TMT A									-.66**
Stroop Word							.60*		
Digits Span Forwards					.54*				
Digits Span Backwards								-.55*	
Hand Dynamometer			-.53**						-.58*

Note. *$p < .05$ are reported with underlining, **$p < .01$ are reported in bold.

Table 4.

Significant correlations for Mean, SD and COV for Angular Displacement and Angular Velocities in the assembly task and cognitive tests

	Both groups			Old group			Young group		
	M	**SD**	**COV**	**M**	**SD**	**COV**	**M**	**SD**	**COV**
Ang. Displacement									
1^{st} interval									
Age				**.64****	.61*				
MMSE				**-.70****	-.53*				
TMT A				**.70****	.60*		.53*		
Hand Dynamometer				-.55*	-.56*				
2^{nd} interval									
TMT A						-.52*			
Stroop Word and Color									.58*
3^{rd} interval									
Age									.55*
TMT A									**.74****
Hand Dynamometer			.43*						
Ang. Velocities									
1^{st} interval									
TMT A				.53*					
2^{nd} interval									
Age				-.61*					
3^{rd} interval									
Stroop Word	**.53****						**.69****		
Stroop Word and Color		.39*			.60*				
Digits Span Forwards			**-.57****						**-.72****
Digits Span Backwards			**-.47****						**-.70****

Note. *$p < .05$ are reported with underlining, **$p < .01$ are reported in bold.

General Discussion

The goals of the present study were a) to evaluate age-related differences in kinematic outcomes on the Purdue Pegboard and b) to assess whether a significant association existed between executive functioning/attention and performance on dexterity tasks. Although no specific hypothesis was stated regarding the cognitive functions, it was a prime of our study to establish differences in cognitive performance between the groups. A discussion for each point of the investigation will be now presented.

Age-related differences on cognitive tasks

As mentioned in the "Method section", none of the participants were excluded from the study after being scored on the MMSE test in order to screen for incipient demented persons. However, the elderly group scored significantly lower than the younger group, which suggests that elderly participants had an overall poorer cognitive status. Interestingly, only results on the Digits Span Forwards and Digits Span Backwards did not show significant differences between groups. These data indicate that the elderly group had good performance in short term memory and working memory.

The Stroop subtests Color, and Word and Color showed significant group differences, confirming a poorer selective attention and difficulties to inhibit inappropriate stimuli of the elderly. This was also true for the Trail Making Tests part A and B, verifying findings from previous research that have shown a slowing of psychomotor functions and a decline in executive functions with growing age (Buckner, 2004). There was also significant differences on Hand Dynamometer, however, this is a difficult result to discuss as further information is needed to do so. The distribution of males and females in the two groups were not even, thus it would be wrong to make assumptions on this particular result.

Concerning the Handedness Inventory we found a somewhat surprising significant difference between groups. Both groups were within the range considered right handed, however, the elderly group had on average the highest scores on this test. It is important to remark that this was the last test run in the testing sessions. As previously mentioned, the elderly participants spent longer time on the testing sessions, and it is of our impression that many of the elders got tired of the many tests and questions. By the time they were tested with the Handedness Inventory, a lot of them displayed signs of irritability and tiredness, and became annoyed of the seemingly repetitive questions in this test. It is hard to tell whether this in fact made them answer to the questions in a rather thoughtless or hasty way. Whatsoever, this must be taken into account when considering the significant group difference found on this test.

In sum, the elderly group showed considerable lower scores than younger adults on the TMT and Stroop test, which confirms that the principal differences between our groups were found on executive functions and not in working memory since the older participants managed well performance on the Digits Span Backwards.

Age-related differences on dexterity

For the first goal of the study, our results showed an age-related difference on performance of the Purdue Pegboard in terms of number of inserted pins and other units all along the different intervals. Although, this finding is not at all surprising our data show that such differences in speed of performance are constant across the different intervals analyzed. The kinematic analyses showed more clearly and in detail these group differences.

Let us start discussing group differences on the inserting pins task. Here, our data showed no significant group differences, which suggest that healthy elderly do not experience any important change in dexterity for simple motor tasks. In contrast, we obtained significant group differences on the assembly task, which is an outcome in accordance with our hypothesis. Regarding angular displacement the elderly group, as compared to the young group, had a slight decrease in variation (i.e. COV) within the 3rd interval. At the same time, variation in the young group increased largely in this interval, revealing a significant difference between the two age groups. A priori, we knew that the elderly increased the number of inserted units at this interval. In spite that this result was not significant, this can suggest that older participants adjusted their hand movements namely by decreasing displacement, they got more proficient in inserting units. This can also be reflected when looking at the young group who displayed opposite effects at both variations in displacement and number of inserted units at the 3rd interval.

As for Mean of angular velocities, analyses showed significant differences between groups on the 2nd interval, also the elderly group performed significantly different across trials. Regarding the difference between groups on the 2nd interval, it seems clear that the elderly participants held a high average angular velocity when performing this task. The young group dropped this initial average velocity already at the 2nd interval, probably to adjust their movements to maintain the speed in which they inserted units. For the young participants this was a successful adaptation. In fact, they managed to insert almost as many units throughout the task. Although, the elders did not insert as many units as the young participants did, they however managed to keep up with their *own* pace, but not through the 3rd interval.

The sudden significant drop in Mean velocity in the 3rd interval may be due just to muscle fatigue, as it also reflects the COV of angular displacement in the same interval which also dropped. Some studies have suggested that there might be age-related changes in the nervous system that leads to muscle fatigue (Davies, Thomas, & White, 1986). So we confirmed that elderly got slower on the assembly task must probably due to fatigue.
On the other hand, COV results are somewhat in opposition to what Cooke, Brown, and Cunningham (1989) have reported about finding elderly subjects with greater COVs as compared to younger persons. It is possible that our analysis by intervals gives a better

understanding of the changes in time on COVs. Actually, the change in COV observed on the young group at interval 3 needs to be discussed. The young participant's movement variability increased more than 300 % to achieve better results at the end of the task. Maybe this specific group difference is an example of what is called in the literature the speed-accuracy trade-off (Spirduso et al., 1995). In fact, Spirduso et al. (1995) states that elders have slower overall movements, take longer to reach peak velocity, and have less smooth movements. When the task in question requires both accuracy and speed as with the dexterity tests in this study, the subject has a tendency to place emphasis on one task over the other. The speed-accuracy trade-off simply means that if the subjects chooses to emphasis speed, accuracy suffers, and vice versa (Spirduso et al., 1995). Heununckx et al. (2005) have found indications of an age-related shift from automatic towards a more directed movement processing with subjects performing isolated flexion-extension movements of the right foot and wrist. And this shift may refer to the assumption that a more controlled processing of movement requires an enhanced attentional deployment. Indeed, the young adults are able to increase their performance most probably because their muscular abilities are more integral than those of the older adults. In any case, our COV data do not support the idea that elderly have higher variability than younger adults at least on this specific task.

The variability of angular velocities, expressed in SD, were significantly different between groups across all trials These outcomes only confirms results of the COV since COV are directly calculated from SD data.

Associations between cognitive tasks and kinematic outcomes

Regarding the second aim of the study, the obtained results showed significant correlations between dexterity measures and the selected cognitive functions, mainly in the older group.

Attentional mechanisms and executive functioning. The inserting pins task: On this task interesting results appeared for the elderly group. As previously stated, we found no differences in the two groups with the Digits Span (DS). However, on the inserting pins task this test (i.e., DS) showed several strong associations with both movement measures in both intervals. These good scores on this test correlated especially with Mean for angular displacement and also with Mean for angular velocities. These effects were only found in the elderly group, maybe suggesting that performance of this test did not matter much to the young's performance, however, elderly with good working memory capabilities had high average movements in their hand while performing the task and this might have helped them to manage the dexterity task. In addition, we found the MMSE to be moderately correlated with the Mean of angular displacements and velocities as well as with the COV in angular displacement. These findings suggest that elderly rely on good working memory capacities and general mental status to accomplish a simple motor speed task in dexterity.

The assembly task: We found several strong associations for variability and cognitive performance of the elderly in the assembly task. First of all, we found important correlations for the elderly group on the Mean and SD of angular displacement with TMT, MMSE and age. There was a general tendency for those with lower scores on cognitive measures to display more variability expressed with SD and COV. This was true for both the TMT A and MMSE in angular displacement, and the Stroop Word and Color and TMT A in angular velocities. These effects were mainly found in the 1st interval, and to some degree in the 2nd and 3rd. This is interesting in light of the dedifferentiation hypothesis (Hedden & Gabrieli, 2004) discussed previously in this paper, as it can be seen from this study that there might be some common cause that affects both motor deficits and cognitive functions. Also, significant correlations in the older group were found on the measurement of angular displacement and not on angular velocities. These data suggest that processing speed and executive functions (as measured by TMT) as well as general appropriate mental status may explain the limited performance in the elderly. What also can be seen from our correlational analyses is that significant associations with age in the elderly group often is opposite from angular displacement to angular velocities. For example, increased age seems to show a high Mean in angular displacement, at the same time they score a low Mean in angular velocities.

In addition to the correlations found in the elderly group, strong correlations were obtained in the young group mainly on angular velocities but also on one movement parameter of the angular displacement, all of them at the 3^{rd} interval. The high correlations were found between COVs and DS, and TMT part A. Further, Stroop Word also correlated significantly with the Mean of angular velocities. These correlations may explain the group difference obtained for the 3^{rd} interval and they suggest that younger individuals rely on the appropriateness of psychomotor functions (as suggested by TMT A and Stroop Word), working memory and short term memory (Digits Span) to increase their performance at the end of the assembly task.

Grip strength (Hand Dynamometer). According to our correlational results from the inserting pins task, a negative significant association was found with COV in angular velocities and grip strength, in both the young group and both groups together. The young participants were, not unexpectedly the group with the most strength of the two. In the assembly task, grip strength was positively associated with COV of angular displacement in both groups together. Overall it looks as though greater grip strength was a factor for holding a low variation in velocity and greater variation in the rotating angle of the hand, or the other way around; the participants with weaker grip tended to display more variation in velocity and less displacement of the angle of the hand. It might be that participants with weaker strength also moves slower, however, we did not obtain significant results for the old group separately on grip strength so this might concern only the young group. It is also important to remark that obviously female participants have naturally less grip strength than males. So it might just be that females in the young group displayed more variation in velocity and less displacement. This study did not look at genders separately, but it might be interesting to look at differences in displacement and velocity for males and females for future research.

Limitations

There are several limitations in this study. With only 15 individuals in each group, this investigation would benefit from more participants.First, with a sample size of only 15 participants in each condition, this study certainly is not based on a large sample. Also, SD of age in the elderly group was quite large, it would be wise to be cautious if generalizing these results to the general population concerning the external validity of this study. Working with this type of motion data was time consuming and unfortunately limited us in the number of participants and number of kinematic variables that could be analyzed in the study. Another limitation concerns the selected cognitive tests. It is possible that other cognitive functions that were not measured on this study could have more impact on dexterity in the elderly.

Future research

In the light of the present findings and this study's limitations, future research should aim to include a lager sample and more restricted age ranges, this is especially true for the elderly group where cognitive and motor decline is rapidly changing. For better movement analyses, future studies might benefit from using 3D kinematic analyses. Many more movement measures should be applied for a better understanding of the hand movements. Also, other statistical analyses such as non-linear analyses should be applied in order to further understand the complexity of hand movements.

The findings on the present study regarding grip strength must be further explored in order to fully understand how the age-related decline in muscle deteriorations truly affects performance on dexterity tasks. Future research should consider to segregate females and males for a fuller understanding of this aspect.

Conclusion

In the present study we found support for the notion that elderly adults performed slower than younger adults in hand dexterity tasks. They did, to a certain extent display more variability in finger movements than the young participants did. However, this effect was strongly recognizable, but seemed to wear off throughout the tasks. Perhaps due to the fact that fatigue and slowing of movements played a bigger part in the chosen dexterity tasks and made finger movements with the elderly subjects stiffer and slower as the task went on. We found strong support for our hypothesis that the elderly participants' performance on dexterity tasks and cognitive tests would show strong associations. These associations were especially made on a cognitively demanding dexterity task were strong associations were found with variability, expressed in SD, and measures of general cognitive state (MMSE), attentional mechanisms (The Stroop) and executive functions (TMT). As expected, group differences for cognitive performance were also detected. These findings tell us that healthy elderly subjects utilize different movement patterns than young adults to perform a dexterity task that is to a certain degree cognitively challenging. The cognitive declines experienced in normal aging may to some extent explain some of these differences. Specifically, it seems that executive functions and attention plays a role in how the elderly execute the dexterity task. However, age-associated declines in grip strength may also play a part in how the elderly perform. Within this field of research it is clear that a deeper understanding on the interaction of changes in dexterity and cognition is needed to fully grasp the effects of aging among the healthy older adults.

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