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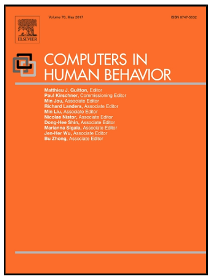

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Typing Competencies in Alzheimer's Disease:

An Exploration of Copy Tasks

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Running title: Typing competencies in AD

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- A carefully constructed typing copy task is proposed.
- A copy task is a useful instrument in the diagnostic work-up of dementia patients.
- A copy task allows for fine-grained measurements at an individual level.
- A copy task combines different aspects of complex and fine motor activities.

Typing Competencies in Alzheimer's Disease:

An Exploration of Copy Tasks

Abstract

Background. The diagnostic work-up of Alzheimer Disease (AD) is complex, time-consuming, expensive, and quite demanding for the patients. Therefore, there is a growing need for simple non-invasive tools that add to the diagnostic work-up of patients.

Objectives. This paper investigates a new method for monitoring motor functions in AD using everyday interactions related to writing with a computer, i.c. executing a copy task.

Methods. An experimental exploratory study was set up in which a carefully designed copy task was presented to three groups of participants: young adults (n=20), cognitively healthy elderly (n=20) and age-matched elderly with mild cognitive impairment (MCI) or mild dementia due to AD (n=12). The task consisted of ten different sub-tasks in which specific bigram characteristics were manipulated. The participants' typing behavior was monitored with keystroke logging.

Results. The three groups differed significantly from each other in performing the copy task. Typing speed gradually decreased with age. Moreover, the cognitively impaired age-matched adults performed slower on all subtasks expressed in longer interkey intervals within the targeted bigrams. Integrative multilevel modelling showed that all the manipulated bigram characteristics contributed significantly to the model.

Conclusion. This explorative study shows the potential relevance of using a typing copy task in the diagnostic work-up of patients with neurodegenerative brain disorders. It relates to a natural task, is non-invasive and easy to automatize. In comparison to other motor tasks it allows for fine-grained measurements at an individual level and combines different aspects of complex and fine motor activities in one task.

Key words: Alzheimer Disease, Computer Literacy, Dementia, Keystroke logging, Mild Cognitive Impairment, Motor Skills, Writing.

Disclosure: The authors have no conflict of interest (financial or non-financial) to declare.

Introduction

Dementia is a general term for a decline in mental ability that is so severe that it interferes with daily life. Dementia, typically characterized by memory loss and language decline, exists in many forms, but Alzheimer's disease (AD) is the most common type. The number of people who suffer from dementia is daunting: One in nine people age 65 and older (11 percent) has Alzheimer's disease (Alzheimer's Association, 2014). Worldwide, nearly 44 million people suffer from Alzheimer's or a related dementia (Prince, Comas-Herrera, Knapp, Guerchet, & Karagiannido, 2016). These numbers will grow exponentially in the upcoming years, as the baby boom generation ages and the number and proportion of persons aged 65 and older increases and becomes more computer literate.

In 2011, the National Institute on Aging (NIA) and the Alzheimer's Association proposed revised criteria and guidelines for diagnosing Alzheimer's disease (AD) (Jack et al., 2011; McKhann et al., 2011). The new criteria and guidelines incorporate two notable changes. First, they identify three stages of AD: preclinical AD, mild cognitive impairment (MCI) due to AD, and dementia due to AD. Second, biomarker tests are incorporated in the research criteria. The main aim of an early, - even preclinical - diagnosis is that many researchers believe that future disease-modifying treatments will enable to slow the progression of AD and preserve brain function (Jack et al., 2011; McKhann et al., 2011).

However, the current diagnostic process is complex, time-consuming and expensive, especially when in the context of longitudinal monitoring, some tests have to be repeated during follow-up. As a result only 1-in-4 people with Alzheimer's disease are being diagnosed. Therefore, in the current study, we have explored whether a non-invasive and simple tool based on an everyday motor activity, i.c. keyboard typing, could be used as an instrument for describing differences in copy typing between healthy elderly and patients in the early stages of AD.

Alzheimer's disease and motor activity

Although little is known about motor function involvement in MCI and AD dementia, the few studies that explored this aspect (e.g., Aggarwal, Wilson, Beck, Bienias, & Bennett, 2006; Giancardo et al., 2016; Kluger et al., 1997; Marquis, Moore, Howieson, & et al., 2002) provide convincing evidence of an association with gradual cognitive impairment. Kluger et al. (Kluger et al., 1997) were one of the first to relate patterns of motor impairment to cognitive decline (in MCI and early AD dementia). They used three different kinds of motor activities (gross motor - fine motor - complex motor tasks) distributed over ten tests and compared the results with tests of memory and language. They found that motor tasks were able to distinguish healthy elderly from cognitively impaired elderly as effectively as the cognitive tests. They also concluded that a loss of complex motor control (e.g. dysdiadochokinesia (DDK), i.e. impaired ability to perform rapid, alternating movements) and fine motor control (e.g., Pegboard fine motor hand coordination) occurs before deficits of gross motor function (e.g. head steadiness or foot-tapping speed). Aggarwal et al. (2006) reached comparable results. In their study they mainly used measures taken from the motor portion of the Unified Parkinson's Disease rating scale. They showed that motor functions in MCI patients were as impaired as compared to participants with no cognitive impairment and were superior to patients with AD dementia.

Typing as a motor activity

As the baby boom generation ages, also the number of seniors that use personal computers in everyday life is gradually increasing. Recent developments in keystroke logging (for a review, see Van Waes, Leijten, Lindgren, & Wengelin, 2015; Van Waes, Leijten, Wengelin, & Lindgren, 2012) show that keyboarding dynamics are a powerful source of input that provides a valuable insight in individual's cognitive, psychological and emotional states. Moreover, typing is considered as a complex motor activity, involving an intricate set of response selection and execution processes (Pinet, Hamamé, Longcamp, Vidal, & Alario, 2014; Sternberg, Monsell, Knoll, & Wright, 1978). Physical and cognitive constraints are an important source of variability in typing, as Salthouse's study (1984) on the effects of age on typing skills already proved. By monitoring computer interaction through keyboarding we further explore this method in the diagnosis of motor activity in MCI and (early) AD dementia, especially because it is also an unobtrusive research technique that allows for accurate activity logging and relates - more and more - to an everyday activity.

West (1967; 1969) distinguished three different stages in the acquisition of typewriting skills: (1) a cognitive phase: learning of different movements related to the keystroke patterns - typists rely mainly on visual feedback; (2) an associative phase: acquired patterns become integrated in a total skill - typists rely mainly on visual (screen) feedback; (3) an autonomous phase: the skill is further automatized - typists mainly monitor their typing by kinesthetic feedback. The decline of typing skills has not been described yet.

Up till now keyboard monitoring has been used in studies about keyboarding skills (Gentner, 1983, 1987; Grabowski, 2008; Inhoff, Briihl, Bohemier, & Wann, 1992; Inhoff & Gordon, 1997), learning disabilities like, for instance, dyslexia (Behrns, Ahlsén, & Wengelin, 2010; Behrns, Hartelius, & Wengelin, 2009; Wengelin & Strömqvist, 2000), but mainly in biometrics studies (Araújo, Sucupira Jr, Lizarraga, Ling, & Yabu-Uti, 2005; Banerjee & Woodard, 2012; Mahar et al., 1995; Rodrigues et al., 2005; Teh, Teoh, & Yue, 2013). To our knowledge keystroke logging has hardly been used in (psycho-)medical studies. The most related studies we could find are those by Vizer et al. (Vizer, 2013; Vizer, Zhou, & Sears, 2009) and Kaye et al. (Kaye et al., 2014). Especially the results of the latter study provides some evidence that observation of typing skills could be "an ecologically valid and efficient approach to track subtle, clinically meaningful change with aging" (p.10) and that computer use might be affected in the MCI-stage. Comparable research is reported by Gunawardhane and colleagues (2013) who also used keystroke dynamics in detecting stress levels.

Apart from these research domains, keystroke logging has been used quite intensively in writing process research during the last two decades (for a review, see Leijten & Van Waes, 2013; Sullivan & Lindgren, 2006; Van Waes et al., 2015). This research technique is especially used to better identify and understand the strategies governing the dynamics of writing (Hayes, 1996, 2012) and the analyses mainly focus on dysfluencies in writing (Alves, Castro, & Olive, 2008; Medimorec & Risko, 2016; Olive & Kellogg, 2002). These are characterized by pauses and revisions, or a combination of both. In writing process research, these dysfluencies are considered to be indicative of the integrity of the cognitive and motor processes underlying written text production (Alamargot & Chanquoy, 2001; Baaijen, Galbraith, & de Glopper, 2012; Matsuhashi, 1981; Wengelin, 2006). The framework for analyzing pauses in written communication mainly stems from research on spoken language (Heldner & Edlund, 2010; Swerts, 1998), but has been adapted to the specific context of writing (Wengelin, 2006) and has the advantage that it is easier to operationalize. Changes in the temporal pattern of interkey intervals are logged by keystroke logging programs and used as a fine-grained basis for analysis. A good example of an adaptation is the introduction of 'P-Bursts' in writing studies, viz. the amount of text being produced between two pauses above a certain threshold (Hayes & Chenoweth, 2006). The length of a P-burst depends on how much language a writer is capable of producing before reaching the capacity limits of the so-called translator.

In the context of the current study, we purposely limit writing to one of its simplest forms, i.e. copying text (Inhoff et al., 1992; Inhoff & Wang, 1992). Copy tasks have been used to create a writing condition in which the cognitive load is low, eliminating to a large extent the higher processes including selection and planning of grapheme production (Grabowski, Weinzierl, & Schmitt, 2010). Therefore, the dynamics of text production in a copy task can be attributed to the very skills of typing (Grabowski, 2008; Wallot & Grabowski, 2013). Moreover, it has been shown that temporal patterns of typing are determined by biomechanical constraints that relate, for instance, to keyboard layout, hand combination and are affected by lexical effects like word and bigram/digram frequency (Gentner, 1988; Gentner, Larochelle, & Grudin, 1988; Inhoff, 1991; Larochelle, 1983; Ostry, 1983; Salthouse, 1984; Sternberg et al., 1978; Taylor Tavares et al., 2005). Wu and Liu (2008) summarized the major factors affecting interkey intervals in copy tasks (or 'transcription typing' as they call it), some of them dating back from pioneering research using video-taped observations of typewriting performance. In their article, they list the main findings in a phenomena list. For instance, in relation to the above mentioned elements that are central in the present study:

> *Phenomenon 7*: Alternate-hand keystrokes are faster than the same-hand keystrokes (called the alternate-hand advantage). Successive keystrokes from fingers on alternate hands are 30-60 ms faster than successive keystrokes from fingers at the same hand.
> *Phenomenon 8*: Digram (letter pairs) that occur more frequently in normal language are typed faster than less frequent digrams (called the digram frequency effect). (Wu & Liu, 2008, p. 5)

A comparable set of variables relating to text production were also used in a more recent study by Pinet et al. (2014). They investigated the underlying neural process of planning in word typing recording electroencephalography (EEG) activities that related to first keystroke onsets (viz. on average first eight strokes). They observed an activation/inhibition pattern over motor cortices similar to that reported in two-alternative forced tasks (choice reaction time tasks). Their data analyses "indicate that both motor cortices are recruited prior to the execution of a first keystroke of a word" (p. 7), clearly demonstrating the importance of inhibitory activities when typing.

Based on these studies, we developed the following hypotheses: (a) a cognitively impaired group shows slower interkey intervals in typing than the age-matched healthy elderly group, and (2) the healthy elderly group performs slower than young adults. Moreover, we expected a frequency effect and hand combination effect related to the characteristics of the bigram that is typed.

Materials and Methods

Study population and diagnostic criteria

The study population consisted of 52 participants, distributed over three groups: 20 young adults, 20 cognitively healthy elderly and 12 cognitively impaired elderly (8 with MCI and 4 with mild AD dementia). All participants spoke Dutch as their mother tongue. Young adults were recruited amongst university students, cognitively healthy elderly were recruited through the researchers' networks and senior centers, and cognitively impaired elderly were recruited in a memory clinic. The participants were recruited between January 2013 and September 2013.

All cognitively impaired participants underwent a diagnostic work-up as described elsewhere (Van der Mussele et al., 2014). To diagnose MCI, Petersen's diagnostic criteria (Petersen, 2004) were applied, i.e. (1) cognitive complaint, preferably corroborated by an informant; (2) objective cognitive impairment, quantified as a performance of more than 1.5 SD below the appropriate mean on the neuropsychological subtests; (3) largely normal general cognitive functioning; (4) essentially intact activities of daily living (basic and instrumental activities of daily living were assessed by a clinical interview with the patient and an informant) and (5) not demented. Probable AD was diagnosed according to NINCDS/ADRDA criteria (National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer's Disease and Related Disorders Association (now known as the Alzheimer's Association), see McKhann et al., 1984; McKhann et al., 2011), though all patients as well fulfilled the DSM-IV criteria (Diagnostic and Statistical Manual of Mental Disorders - Fourth Edition, see American Psychiatric Association, 1994; McKhann et al., 2011; Petersen, 2004). The inclusion criteria for the healthy elderly (HE) group were: no history of neurological or psychiatric disorders and no organic disease involving the central nervous system.

The cognitively healthy participants were matched to the cognitively impaired participants based on age and computer literacy (typing on AZERTY-keyboard). The participants were all assessed at the time of the study using the Mini-Mental State Examination (MMSE, see Folstein, Folstein, & Mc Hugh, 1983) and the Geriatric Depression Scale (GDS, see Burke, Houston, Boust, & Roccaforte, 1989). Only those participants were included that scored below 12 (max. 30) on the GDS –indicating that they did not suffer from (severe) depression–, above 24 (max. 30) at the MMSE and without a history of cognitive/motor impairment that can influence writing processes (e.g., dyslexia, AD(H)D). Basic computer keyboarding skills were used as an inclusion for both the control and experimental groups.

The mean age of the group of 20 young adults was 22.5 years (*sd*=1.0); of the 20 healthy elderly 74.3 years (*sd*=5.8), and of the 12 cognitively impaired elderly 73.9 years (*sd*=4.3). A Mann-Whithney test indicated that there was no significant difference for age between the group of healthy and cognitively impaired elderly (U = 112.500, Z = -.293, p = .770). The mean score on the MMSE and GDS was respectively 28.5 (*sd*=1.9) and 5.6 (*sd*=3.0) and for the cognitively impaired 26.3 (*sd*=1.7) and 9.2 (*sd*=6.0). The mean scores on the MMSE for both groups showed a significant difference (U = 37.50, Z= -3.03, p <.005). However, both scores are well above 24 points (out of 30) indicating a normal cognition. The mean score comparison for the GDS was not significant: (U = 51.50, Z = -1.85, p = .064).

The study was reviewed and approved by the local ethical committee. All patients and/or patients' caregivers gave written informed consent.

Materials

A set of sixteen bigrams characterizing differences in frequency and hand combinations (2*4 design with at least two targeted bigram items in each condition) was selected. The frequency of the bigrams was drawn from the CELEX Lexical Database of the Dutch Centre for Lexical Information (CELEX, see Baayen, Piepenbrock, & Van Rijn, 1993). Bigrams were selected in respectively the group of the 30% most frequent bigrams (e.g., *le* or *ie*) and 30% less frequent bigrams (e.g., *ao* or *ow*). Next, within each frequency group, we selected bigrams that differed on the basis of the hand combination needed to produce that bigram (on a Belgian azerty keyboard): right-left, left-right, right-right, left-left (Salthouse, 1984). Because not all participants were touch typists, we avoided bigrams of which one character was situated in the mid zone of the keyboard.

These selected bigrams were carefully implemented in words and sentences used as the basis of a copy task. We distributed the bigrams in such a way that they never occurred at the beginning or end of a word so as to avoid anticipated or delayed between word latency effects (Maggio, Lété, Chenu, Jisa, & Fayol, 2012). This copy task comprised ten parts (cf. Table 1).

Design and Procedure

We designed a copy task that contained ten components (Table 1). The main parts of the copy task require different copy skills, and address a variety of motor and semantic competencies and different levels of automaticity (Grabowski, 2008; Grabowski et al., 2010; Yamaguchi, Crump, & Logan, 2013).

Table 1. Overview of the ten different parts of the copy task

0	**test sentence**
1-2	**sentences** copy a sentence (approximately 15 words)
3-5	**words** copy a combination of two words 10 times (e.g., *bedankt cowboy [thanks cowboy]*)
6-7	**pseudo-words** copy a combination of two pseudo-words 10 times (e.g., *mensitie lakeurig*)
8	**words from memory** copy a combination of two words (the words disappeared just before typing)
9	**numbers** copy four blocks of six numbers (Grabowski et al., 2010)
10	**consonants** copy four blocks of six consonants (Grabowski et al., 2010)

The experiment was administered individually to the elderly participants and took about 10 to 15 minutes; the younger group was tested in small groups. All participants performed the tests seated comfortably before a personal computer in a quiet room. To accommodate the participants to the environment and the writing task itself, they were asked to copy a short on screen sentence first. When this task was completed successfully, the controlled copy task was started. The basic instruction was: "In this session we will ask you to type letters, words and sentences that are shown on the screen. Try to do this as fast and error free as possible. If you make a mistake, it is not necessary to correct it. Typing mistakes are no problem. You can just continue typing. Correctness is less important than your typing speed." All information was presented on screen. To limit fatigue effects, the copy task was split in two, and presented as two separate tasks. The participants were also allowed to pause after each subtask.

Apparatus

The process data were collected with Inputlog 6 (www.inputlog.net - Leijten & Van Waes, 2013). Inputlog is a keystroke-logging program that has been developed to collect all keyboard and mouse activities during text production. Since this program also adds a time stamp (ms) to each logging event, the resulting log files can be analyzed to explore the dynamics of the writing process from different perspectives. Inputlog offers by default some predefined analyses. In the context of this study, mainly the so-called general analysis was used (Leijten & Van Waes, 2014). Apart from some metadata, this analysis represents the logging process as a fine-grained dataset containing all keystrokes, mouse movements and their respective time stamps in linear order. Each line in the output represents a keystroke (or mouse action), which is documented with position and time-based information (key-in and key-out time in ms) which is used to calculate inter-bigram latency or pause time (time between two consecutive key-in actions).

Analysis

For the analyses of the copy task the data were approached from two perspectives: on the one hand all bigrams were taken into account and on the other hand the analyses were restricted to the manipulated bigrams only. The inter-bigram pauses were trimmed at a 95% confidence interval and with a threshold of 50 ms (to exclude slips of the fingers).

Finally, all the data were analyzed using IBM SPSS Statistics (v. 22). Differences between the three groups, the different bigrams and the different parts of the copy task were calculated with multivariate analyses of variance (between-subjects Manova) and General Linear Models (within-subjects repeated measures, corrected for sphericity - Greenhouse-Geisser - if necessary). Finally, a multilevel analysis (MLWin v. 2.19) was used to synthesize the results in an overall analysis taking into account the hierarchical structure of the data (Leijten, De Maeyer, & Van Waes, 2011).

Results

The results are presented from different perspectives. First, the different parts of the copy task were analyzed and the interkey latency for the three groups were compared. Next, the results of the repetitions produced within the word combination tasks were presented (task 3 to 8). In the final section the results were analyzed taking into account the manipulated bigram characteristics (frequency and hand combination).

Parts of the copy task

In a first analysis of the logged data the different parts of the copy task were compared across the three groups. In this analysis all the inter-bigram transition latencies were taken into account (95% trimmed - lower threshold >50 ms). All key combinations that did not result in a letter bigram combination (except for the last part of the copy task) were excluded. This resulted in about 700 observations per person (M=703; SD=88), spread over the different parts of the copy task. Figure 1 represents the average pause length that characterizes the overall latency between two subsequent characters in a produced bigram.

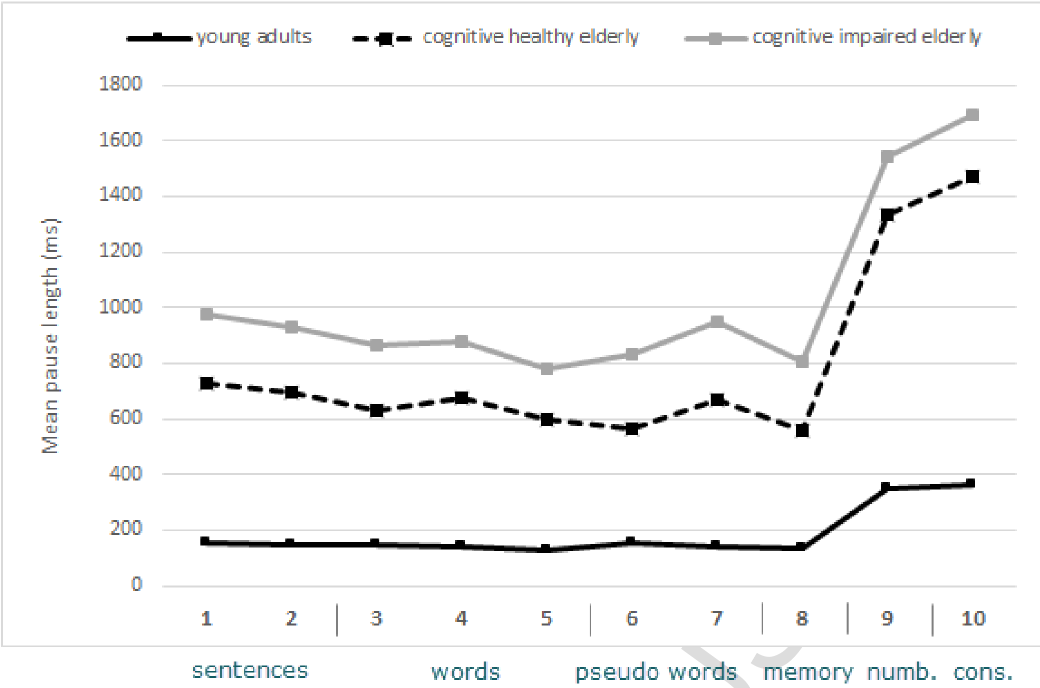

Figure 1: Average pause length (95% trimmed) for the inter-bigram transitions in the different parts of the copy task.

As shown in Figure 1, the different copy tasks resulted in a comparable pausing pattern for the three groups of participants. There was a main effect for the part of the copy task (F(3.1,139.6)=114.6; p<.001; η_p^2=.718), but a post-hoc Bonferroni showed that this was mainly related to the last two tasks (that differ significantly from the word and sentence copy tasks). These two tasks (copying a series of numbers and consonants without any semantic reference) were performed significantly slower than the other tasks, indicating a significant higher load on the participants' working memory due to the relative complexity of these task (Olive, 2012, 2014). The copy task in which the participants did not copy a word combination directly from screen, but based on memory (task 8) did not deviate significantly from the previous copy tasks, for none of the participants.

In general, the length of the inter-bigram pauses differed significantly between the three groups: F(2,45)=35.7; p<.001; η_p^2=.613. On average the inter-bigram transitions of young adults were about 75% shorter than those of the healthy elderly; and the transitions of the latter group were about 25% shorter than those of the cognitively impaired participants (AD group): resp. M=192 ms, 784 ms and 1059 ms; SD= 32, 304 and 433). Post-hoc analysis (Bonferroni) revealed significant differences between the young adults and the two other groups, for all tasks ($p<.001$), and between the latter two groups ($p<.01$), especially for copy task 1, 6 and 8.

Repetitive copy task

In a second analysis we focused on the copy tasks in which the participants produced a word pair repetitively (10 times). Figure 2 shows the result of this analysis.

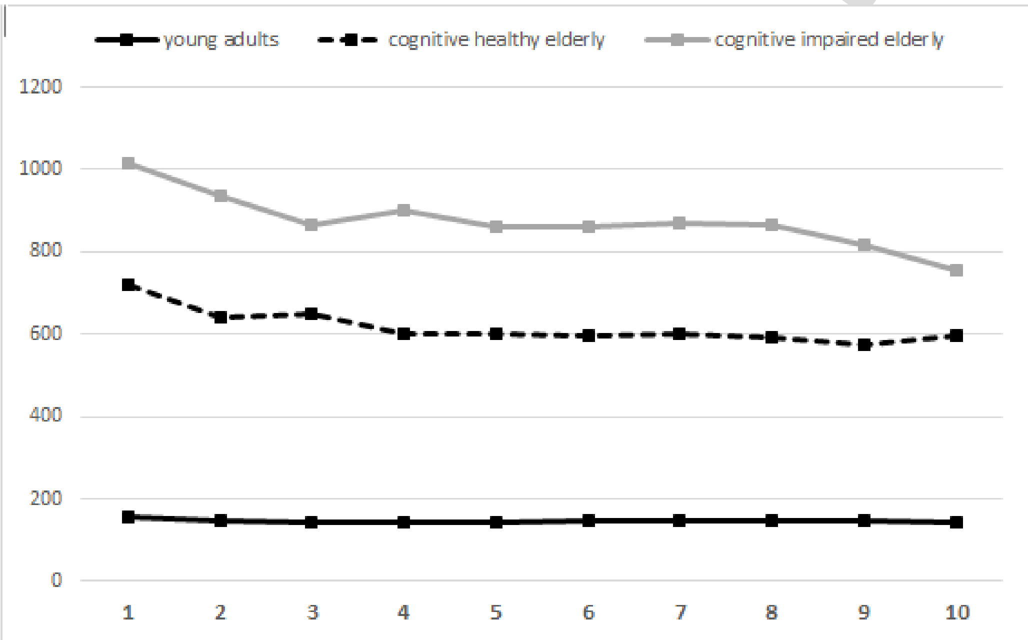

Figure 2: Average pause length in ms (95% trimmed) for the inter-bigram transitions for the 10 trials in the copy task (part 3 to 7).

The three groups differed significantly from each other with respect to the fluency in producing these word combinations repetitively: $F(2,49)=25.4$; $p<.001$; $\eta_p^2=.509$. The post-hoc analysis revealed that there was a significant difference between all the three groups (resp. young adults vs the other two groups $p<.001$; healthy vs. cognitively impaired: $p<.05$). Moreover, the analysis showed that in general there was a gradual decrease of the pause length ($F(5.5,271.6)=13.67$; $p<.001$; $\eta_p^2=.218$). In other words, after about two trials the speed of typing a bigram increased which might be related to a practice and accommodating effect. Overall, on the trial level, only the first trials significantly differed from the other trials (Bonferroni multiple pairwise comparison *p*<.05); the first trial was performed slower.

Bigram characteristics

Figure 3 shows an analysis in which the production of low and high frequency bigrams are compared (for word and sentence production tasks 1 to 8). The GLM repeated measures ANOVA showed both a significant effect of frequency ($F(1,50)=119.6$; $p<.001$; $\eta_p^2=.705$) and group membership ($F(2,50)=32.6$; $p<.001$; $\eta_p^2=.566$). On average the targeted high frequent bigrams were produced 26% faster than low frequency bigrams; a relative increase in speed in the production of high frequency bigrams was quite constant over the three groups. A pair-wise comparison (post-hoc Bonferroni) showed a significant difference between all the three groups (resp. between the young adults and the two others: *p*<.001, and between the healthy and the cognitively impaired elderly: p<.05).

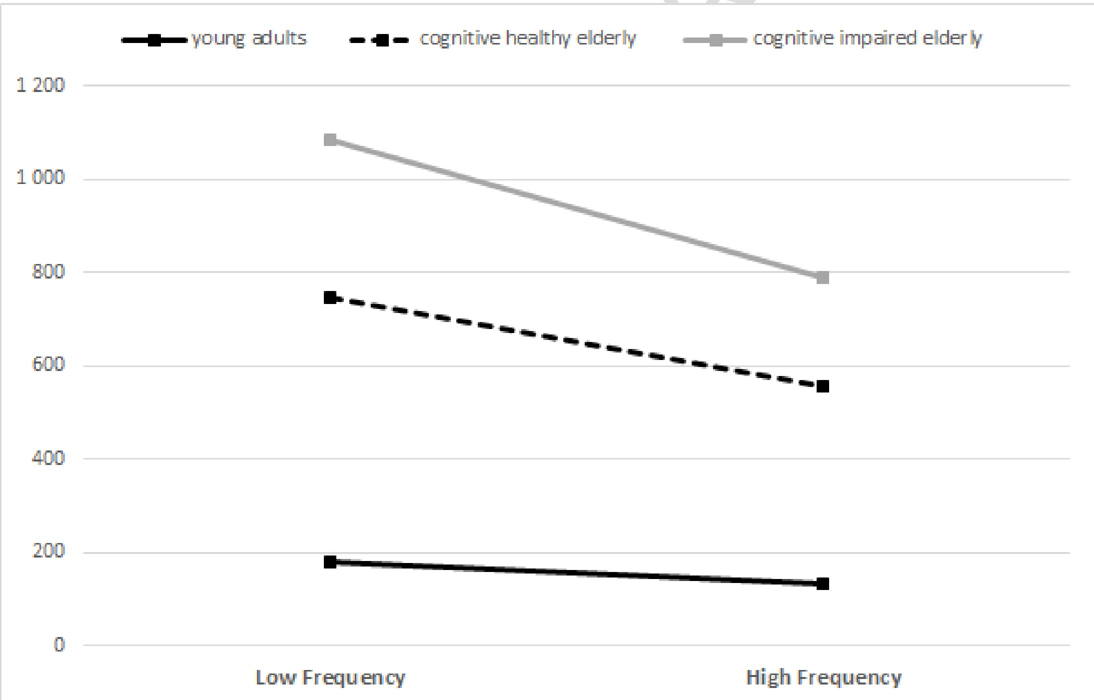

Figure 3: Average pause length in ms (95% trimmed) for the transitions within low and high frequency bigrams (tasks 1 to 8).

Because also the hand combinations that were needed to produce the bigrams were varied in the copy task, the within participant differences that relate to this motor characteristic were analyzed as well. **Figure 4** shows the results of this analysis. Again there was a significant main effect between the different groups of participants ($F(2,49)=213.1$; $p<.001$; $\eta_p^2=.564$), as well as a pairwise effect (post-hoc Bonferroni) between all the three groups (resp. between the young adults and the two others: $p<.001$, and between the healthy and the cognitively impaired elderly: $p<.01$). There also was a significant main effect related to the hand combination involved in the production of the bigrams ($F(2.3,115.8)=36.4$; $p<.001$; $\eta_p^2=.426$). For the students only the left-left combination deviated from the other hand combinations. However, for the other two groups the hand combinations seemed to be a more important determining factor. Especially the difference between the left-right and the right-right bigrams was considerable: the bigram latency for the latter group was on average 35% (healthy elderly) and 39% (cognitively impaired elderly) shorter[1].

[1] For these data no information about handedness was collected, but it might be the case that results are affected by hand preference. Overall, about 10 percent of the population is considered to be left-handed. In each of the elderly groups only one person realized the right-right combination slower than the left-right combination. In these cases there was also a slower left-left same hand combination.

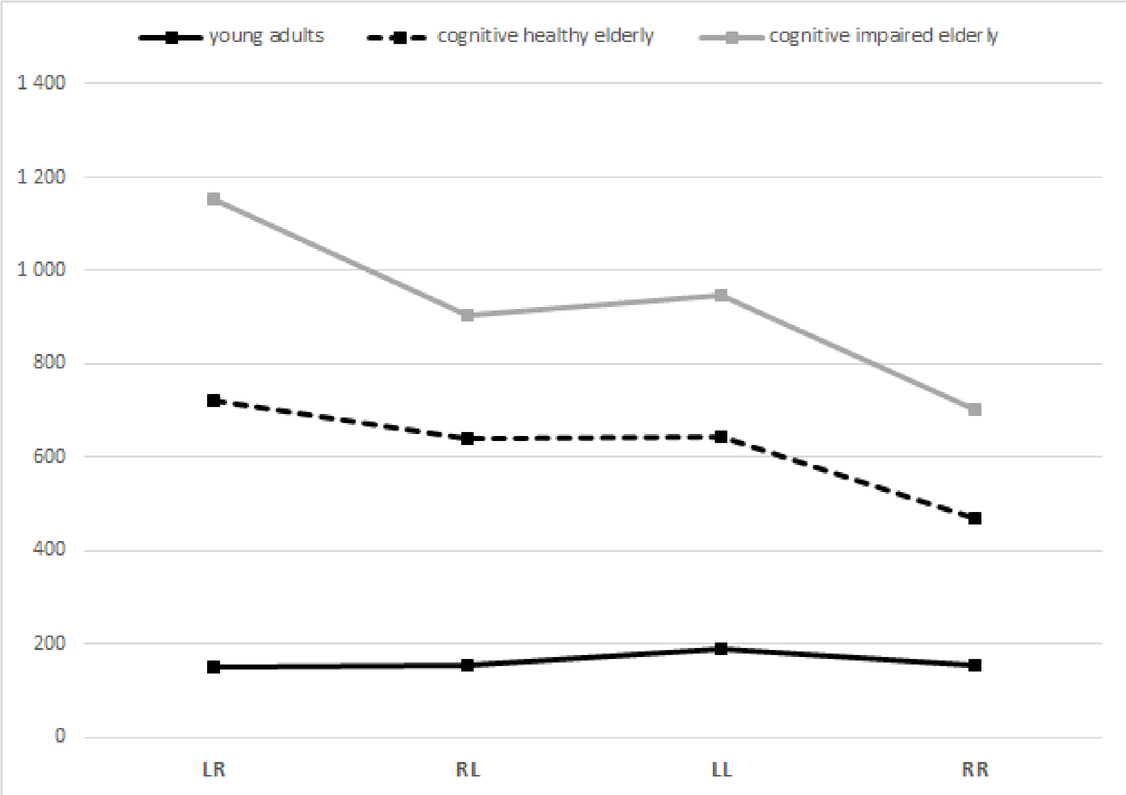

Figure 4: Average pause length in ms (95% trimmed) for the inter-bigram transitions produced by resp. a left-right (LR), right-left (RL), left-left (LL) and right-right (RR) hand combination.

Finally, to better take into account the hierarchical character of the data, an integrative multilevel model was created in which we included the groups at the highest level, and the targeted bigrams at the lower level. Frequency and hand combination were added as independent variables at this level. Table 2 shows the comparison of the stepwise created models. Low frequent bigrams were used that were produced with left-right hand combination as a reference modus. All independent variables contributed significantly to the models. The Chi Square analysis comparing the different models, showed that the last model - that includes both frequency and hand combination - proved to be the most powerful ($\chi 2(7)$; $p < .001$).

Table 2: Comparison of the stepwise created multilevel models for the trimmed intra bigram transition time

	model 0		**model 1**		**model 2**		**model3**	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Fixed Part								
cognitively impaired elderly			939	10	934	12	978	20
cognitively healthy elderly			669	5	671	6	664	10
young adults			160	1	184	2	191	4
high frequency					-55	2	-52	4
hand combination								
left-left							24	5
left-right							-21	5
right-right							-23	6
constant	590	187						
Random Part								
level: 3 groups								
cons/cons	104324	85256						
level: code								
cognitively impaired elderly			938681	14170	858257	16236	987891	28202
cognitively healthy elderly			413307	4871	374863	5498	384204	8486
young adults			15780	188	13130	196	14053	316
cons/cons	387069	2837						
-2*loglikelihood:	584787		548495		348401		154159	
units: Group_3	3		3		3		3	
units: code	37236		37236		23854		10513	
Chi Square			<.001		<.001		<.001	

The fixed part of the analysis showed that in comparison with cognitively impaired elderly the healthy elderly needed about 68% of the transition time to type a bigram in this copy task (model 3): *M*=978 (*SE*= 20) vs. *M*=644 (*SE*=10). For the young adults it dropped to about 20% (*M*=191 (*SE*= 4). All the bigram characteristics contributed significantly to the model. Typing a high frequent bigram letter combination required on average 52ms less time. Moreover, taking the right-left hand combination as a reference, the left-left hand combination slowed down the process with about 24ms; while the left-right and the right-right hand combination accelerated the process, respectively with 21 and 23ms.

Discussion

This research explored the possibility of monitoring keyboard interactions to detect gradual changes in motor performance related to aging and cognitive decline due to AD. Three groups of participants (n=52) were included: 20 young adults, 20 healthy elderly and 12 elderly with MCI or mild AD dementia. The typing task consisted of a low cognitive load copy task in which different types of bigrams (varied for frequency and hand combination) were implemented in words that needed to be copied (repetitively). The typing process was observed and registered with keystroke logging (Inputlog). The fine-grained process data allowed to measure and analyze the latency of the interkey intervals. The results of these cross-sectional analyses demonstrated a pattern of diminished motor control related to typing, respectively between young adults and cognitively healthy elderly, and between cognitively healthy elderly and the group of cognitively impaired patients. Integrative multilevel modelling showed that all the bigram characteristics that were manipulated in the task (frequency and hand combination) contributed significantly to the model.

While these tests cannot replace other types of neurobehavioral testing in neurological populations, we contend that they could provide valuable additional information when making a clinical judgement on the cognitive and motor status of an individual. Understanding the nature of (complex and fine) motor decline related to typing - in this case in the context of a copy task - might constitute a valuable complementary tool in the detection and evaluation of (early) AD.

One of the advantages of using a typing copy task to assess motor skills is that these type of tasks combine an interesting subset of fine and complex skills including sensory-motor integration, motor choice, sequencing and speed of movements. As Kluger et al. (Kluger et al., 1997) concluded, especially performance related to these kind of motor skills are good discriminators for the diagnosis of AD. The advantage is that they are combined within one natural task, and do no longer require separate sets of different motor tasks to be assessed in complex, artificial contexts. As such, task execution is also not influenced by educational level (Kluger et al., 1997). Moreover, the nature of the task and the way in which the process data are logged allow for fine-grained observations (accuracy level of 7 ms) and analyses (in contrast with, for instance, the subjective coarse-grained scale that is often used in finger-tapping tasks (Taylor Tavares et al., 2005)). Due to the fact that the data are collected digitally it is also possible to further automatize both the collection procedure (e.g., using a web application) and the analyses. This is an important factor when the copy task is used to monitor longitudinal development in performance (within-subjects design). As Albert et al. (2011) state, it is important to obtain objective evidence of progressive declines over time "for establishing the accuracy of the diagnosis, as well as for assessing any potential treatment response."

This study also has a number of limitations. Firstly, it had an explorative character, and only a limited number of persons participated in the study, especially in the cognitively impaired group. Moreover, although we carefully matched the cognitively healthy elderly with the impaired group based on age and computer literacy, it might be advisable to also evaluate other matching criteria like education and reading fluency.

Follow-up studies are needed to replicate the current findings, also focusing explicitly on different types and stages of AD and related neurodegenerative brain disorders. To further optimize the hand combination analysis, we argue that future studies should implement a standardized handedness test (Fazio, Dunham, Griswold, & Denney, 2013; Oldfield, 1971). Moreover, at the moment larger scale data collection might be partially restricted because not all elderly master typing skills, but this is only a temporary phenomenon. Another limitation of the current study might be the length of the copy task. While the length of the copy task (10 subtasks) was not problematic for the young adults, the elderly participants sometimes reported that they experienced the task as fatiguing. Especially, the fact that some tasks required them to copy the entry repetitively (10 times) seemed to make this copy task quite strenuous for some of them. Therefore, further analyses are needed to shorten the copy task without losing testing power. This is especially important if this motor task is used in combination with other writing tasks that are cognitively more demanding than a copy task (Leijten, Van Horenbeeck, & Van Waes, 2015; Wallot & Grabowski, 2013). From our perspective, this would mean that it should be possible to compose an individual's baseline interkey latency from the current copy task and use this as a motoric baseline in a more complex writing task. When enough data are collected, it will become possible to position individual measures to (sub)group measures relatively as well.

In conclusion, we contend that a typing copy test might provide valuable information in the diagnostic work-up of patients with neurodegenerative brain disorders. It relates to a natural task, is non-invasive and easy to execute and automatize, and very suitable for longitudinal monitoring. In comparison to other motor tasks it allows for fine-grained measurements at an individual level and combines different aspects of complex and fine motor activities in one task. Moreover, we advise taking into account typing competency measures in writing process research studies focussing on low-level processes.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee.

Informed consent

Before starting the measurements, each subject was provided with an oral explanation of the full procedure and signed an informed consent, following approval of the study by the ethical committee UZAntwerpen (Belgium).

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Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee.

Informed consent

Before starting the measurements, each subject was provided with an oral explanation of the full procedure and signed an informed consent, following approval of the study by the ethical committee UZAntwerpen (Belgium).