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Distinguishing Early Alzheimer's Disease from Normal Ageing:

A Time Course Analysis of Clustering and Switching

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Master's Thesis in Psychology PSY-3900 – May 2016





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CLUSTERING AND SWITCHING THROUGH TIME IN EARLY AD

Foreword

On the occasion of my master's thesis in psychology at the University of Tromsø, I got to be part of a project under the leadership of Associate Professor Claudia Rodríguez-Aranda. This project concerned verbal fluency in groups of healthy young and older adults, and patients with early Alzheimer's disease, for which testing procedures had already taken place from 2008-2012. As part of a larger project, data had previously been used in the main thesis (in the clinical degree course in psychology) by Ann-Helen Holmen and Guro Strand Thorbjørnsen. Based on these data, my master's thesis involved intricate, detailed, and very time-consuming analyses of recorded verbal fluency performance. Analyses and the written account were performed by me, while statistical analyses and interpretation of results were done with valued guidance and in cooperation with Claudia Rodríguez-Aranda. My supervisor also stood for the first parts of the graphical presentation of results, and I am grateful to use this material in my thesis.

CLUSTERING AND SWITCHING THROUGH TIME IN EARLY AD

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At last, thanks are also in order to my fellow students, for valuable support and friendship.

CLUSTERING AND SWITCHING THROUGH TIME IN EARLY AD

Sammendrag

En av de kognitive svekkelsene som rammer pasienter med mild Alzheimer's sykdom (AD) angår evnen til å produsere ord, gjenspeilet i verbal flyt (VF). Tidligere forskning har undersøkt mål på VF (korrekte ord, repetisjoner, og feil) hos pasienter i tidlig fase av AD i en tidsanalyse. I en utvidet replikasjon vil denne studien inkludere clustering og switching i en tidsanalyse. 24 friske unge, 23 friske eldre, og 19 AD-pasienter gjennomførte fonemiske og semantiske VF-tester. Clustering, sammen med korrekte ord, reflekterte semantisk minne, switching, repetisjoner og feil pekte på eksekutive funksjoner, og intervaller (mellom hvert ord) indikerte prosesseringshastighet. Målene på VF ble fortolket relativt til to perioder på 30 sekunder hver. Friske eldre hadde flere repetisjoner i siste halvdel av minuttet på fonemisk VF. På semantisk VF hadde de svekket clustering de første 30 sekundene, og svekket switching de siste 30 sekundene. Samlet peker svekkelsene på eksekutiv dysfunksjon. AD-pasienter produserte færre ord, flere repetisjoner, og lengre intervaller i de første 30 sekundene, men bare på semantisk VF. Clustering var svekket kun på fonemisk VF, i de siste 30 sekundene. Dette indikerer svekkelse i semantisk minne, prosesseringshastighet, og mulig eksekutiv funksjon, og kan også se ut til å følge en abnormal utvikling. En tidsanalyse av clustering og switching viser potensial til å kunne skille mild AD fra normal aldring. Det er behov for videre forskning, da mer kunnskap om mekanismene i patologisk aldring er viktig for diagnostisering og behandling av pasienter med mild AD.

CLUSTERING AND SWITCHING THROUGH TIME IN EARLY AD

Abstract

An impairment emerging in the early course of Alzheimer's disease (AD) concerns the ability to produce words, reflected in verbal fluency (VF). Previously, a time analysis of correct words, repetitions, and intrusions has been done, and this study aims to expand this time analysis by introducing clustering and switching. 24 healthy young adults, 23 healthy older adults, and 19 patients with early AD performed phonemic and semantic VF tests. Clustering, together with the number of correct words identified semantic memory capacity, switching and errors reflected executive functions, and inter-item latencies indicated processing speed. Scores were analysed relative to 30 second periods. Healthy elderly had more repetitions in the first 30 seconds in phonemic VF, poorer clustering during the first 30 seconds, and poorer switching the last 30 seconds, both in semantic VF. Older age thus bring expected executive dysfunction. AD patients produced fewer words, more repetitions, and longer inter-item latencies during the first 30 seconds in both tasks, but especially in semantic VF. Also, phonemic clustering was impaired during the last 30 seconds. AD patients suffer from abnormal semantic memory detriments and slowing of processing speed, in addition to executive dysfunction. Phonemic clustering differentiated AD patients from healthy elderly, but only semantic VF impairments in memory and processing speed appeared abnormal in terms of time. Clustering and switching evaluated in a time course analysis shows potential of delineating possible abnormalities in VF in AD, and should be further investigated to increase the knowledge of VF in early AD.

The population is gradually reaching an older age, which often brings cognitive impairment, including symptoms of memory loss, difficulties with self-monitoring and planning, and also problems in language and speech. In healthy ageing, it is suggested that cognitive processes change as a function of age alone (Goh & Park, 2009). Healthy older adults may experience a slowing of information processing (Rodríguez-Aranda, Waterloo, Sparr, & Sundet, 2006), forgetfulness, and executive dysfunction, but not to the extent to which daily life functioning becomes problematic. For patients with AD, however, the symptoms are thought to be of pathological character, in which underlying mechanisms seems to involve progressive degeneration of neural tissue (Collette et al., 1999; Gaugler, James, Johnson, Scholz, & Weuve, 2014; Pantel, Schonknecht, Essig, & Schroder, 2004; Schuff et al., 2012). Cognitive dysfunction is likely to follow a distinct path compared to normal ageing, both in terms of impact, severity, progression, and implications in daily life functioning.

Language Impairments in Early AD

One disability emerging in the course of AD, and that differ in impact and severity from normal ageing, concerns language. Deteriorations of language abilities in the course of AD more specifically involve the impairment of efficient word production. In normal ageing, words may also be forgotten or difficult to retrieve, but this experience follows as a natural part of ageing, as the brain is thought to be less specialized, and more generalized (Kavé & Knafo-Noam, 2015). For patients with AD, these deficits appear to be of a more severe character, and deterioration is thought to be due to pathological mechanisms, rather than being caused by age alone. Already at the early stage of the disease, patients may fail to recall words and replace these with faulty words or perseverations (Suhr & Jones, 1998), and also generally spend more time on searching for, selecting, and generating their responses (McKhann et al., 2011).

Verbal Fluency as an Indicator of Language Impairment

One way to evaluate retrieval and efficient production of language in ageing populations is by the use of *verbal fluency* (VF) tests. VF means producing words in a rapid and efficient manner, requiring that one must hold knowledge and be able to retrieve this information quickly in a limited frame of time. The term VF was first coined by psychometrician Louis Leon Thurstone in relation to conducting a factor analysis to determine what components intelligence consisted of. He found word fluency and verbal comprehension to make two of seven factors (Thurstone, 1938).

In practice, VF is assessed by presenting the participant with *phonemic* (also referred to as letter) and *semantic* (or category) stimuli, and having the subject producing words in accordance with the given stimulus. Performance is reflected by the number of correct words produced. Intrusions and repetitions, collectively referred to as errors, are excluded in the standard scoring. In the following sections the types of VF tests will be described. Following, variables that may moderate VF performance are briefly presented.

Phonemic VF. In a phonemic VF task (also known as the Controlled Oral Word Association Test (COWAT; Benton, 1968), the subject is required to produce as many words as possible starting with a given letter (usually *F*, *A*, and *S*) during the time of one minute. In addition there are specific rules (Troyer, Moscovitch, & Winocur, 1997), addressed in more detail later in the text. To perform in phonemic VF (Shao, Janse, Visser, & Meyer, 2014) one must to be able to selectively search for words in lexical memory stores that fulfil the criteria one is confronted with, and self-monitor the process of retrieving the word and expressing it. What is more, one needs to avoid perseverations through the process of sustaining and updating information in working memory, and inhibiting words violating the rules of the task to avoid intrusions (Wingfield & Kahana, 2002). These processes are considered parts of executive

functions that are associated with the frontal lobe, and performance may therefore also depend on the function of this part of the brain (Hirshorn & Thompson-Schill, 2006).

Semantic VF. In the semantic VF task (Newcombe, 1969), almost the same conditions as for the phonemic test apply, except that generated words must be in accordance with a given category (e.g. *animals*). Performance requires executive functions and, to a larger degree than phonemic VF, access to memory stores, specifically those holding semantic information. Semantic VF seems to be a somewhat automatic process (Fernaes & Almkvist, 1998), compared to the more effortful phonemic VF task, because of how one response (i.e. word) will activate another that shares similar properties with the first response. Therefore, having intact semantic memory stores and the access to these (Rohrer, Wixted, Salmon, & Butters, 1995), which also implies the functioning temporal lobes of the brain (Jones, Laukka, & Bäckman, 2006; Stuss et al., 1998), is very important in order to perform in this VF test.

Now, it is important to note that although semantic VF may equally rely on appropriate memory capacity and executive function, phonemic VF depends to a larger degree on EF. Apart from these two main cognitive abilities, speed of processing is of extreme importance to achieve a good performance on the VF tasks (Salthouse, 1996), given the time restriction of one minute per letter or category.

Factors Affecting VF Performance

There are some moderating variables influencing VF performance. In this section, the most studied will be presented.

Sex. Scores in VF tests have been suggested to vary between sexes, in which males have been found to perform better than females (Auriacombe, Fabrigoule, Lafont, Jacqmin-Gadda, & Dartigues, 2001). However, most of the findings have only approached significance (Brucki &

Rocha, 2004; Haugrud, Lanting, & Crossley, 2010; Mathuranath et al., 2003), and studies have also failed to confirm these suggested sex differences (Gladsjo et al., 1999; Troyer, 2000).

Education. VF performance is suggested to depend on education, as individuals with more academic training do better, both in phonemic and semantic VF (Gladsjo et al., 1999; Stockholm, Jorgensen, & Vogel, 2013; Troyer, 2000; Zhao, Guo, & Hong, 2013; Zimmerman, Parente, Joannette, & Fonseca, 2014).

Vocabulary. It is related to education, but perhaps vocabulary is a more stable predictor through life (Auriacombe et al., 2001; Federmeier, McLennan, De Ochoa, & Kutas, 2002). Knowledge of words has been noted as a predictor of VF performance, both in the phonemic and semantic task (Rodríguez-Aranda et al., 2006; Shao et al., 2014; Tombaugh, Kozak, & Rees, 1999), although phonemic VF and vocabulary may seem to be more closely associated (Troyer et al., 1997). Vocabulary and education are closely related, but the knowledge of words seems to be distinct as older adults have been found to outperform younger adults similar to them in terms of education (Federmeier et al., 2002). In spite of the suggested decline of knowledge acquired through formal education (Zimmerman et al., 2014), vocabulary increases with age (Kavé & Knafo-Noam, 2015; Troyer et al., 1997).

Age. Another very important predictor of VF is age, which also has moderating effects on both education and vocabulary. Research has revealed the impact of this factor on VF performance (Auriacombe et al., 2001; Gladsjo et al., 1999; Zimmerman et al., 2014). Age often brings decline in search and retrieval processes, semantic memory, and processing speed (Goh, 2011; Salthouse, 1996; Wingfield & Kahana, 2002), but with inconsistent results that make it difficult to understand the exact mechanisms underlying the decline. Age is a variable of interest in the present study, and will in the following section be further addressed in relation to VF performance, before giving an account of VF performance in early AD.

Phonemic and Semantic VF Performance in Normal Ageing

Age has been suggested to have negative impact on VF compared to younger adults (Haugrud et al., 2010; Rodríguez-Aranda & Jakobsen, 2011), and some have pointed to the semantic VF as more vulnerable (Gladsjo et al., 1999; Mathuranath et al., 2003; Rodríguez-Aranda et al., 2006; Troyer, 2000). However, decline also applies to phonemic VF performance (Rodríguez-Aranda & Martinussen, 2006; Tombaugh et al., 1999). A possible explanation for why the semantic task reflects the larger age differences may be because it requires both semantic memory capacity and executive function, making the task more cognitively demanding (Kavé & Knafo-Noam, 2015). Therefore, one must selectively retrieve both concepts and phonological information from memory.

On the phonemic task, activating a concept might not be as central, and the requirements of memory capacity are thus lower in this type of task. Nevertheless, other researchers have stated the phonemic task is more difficult, as it requires effortful, efficient, and rapid processing of information (Fernaes & Almkvist, 1998; Zimmerman et al., 2014). Impaired VF performance has been argued to lie in poorer executive function (Mayr & Kliegl, 2000). This should suggest a higher rate of errors in VF assessment, although these rates are generally small (Gomez & White, 2006; MacKay & Burke, 1990). Alternatively, increasing the speed of processing could impact other executive functions, and thence increase the rate of errors. Thus, others claim poorer VF has more to do with failing to retrieve information from memory stores in a time-efficient manner, hence a declining processing speed (Burke, MacKay, Worthley, & Wade, 1991; Goh, 2011; Salthouse, 1996).

Phonemic and Semantic VF Performance in Early AD

Although age may bring subtle deficits in VF performance relative to younger individuals, AD patients' impairments are more pronounced. Patients are generally outperformed

by age-matched controls, and produce fewer words on both the phonemic and semantic VF task (Epker, Lacritz, & Munro, 1999; Murphy, Rich, & Troyer, 2006). Consequently, they produce more errors, especially perseverations (March & Pattison, 2006). However, the semantic component of VF seems to be affected to a larger extent in patients than the phonemic VF (Holmen & Thorbjørnsen, 2013; Murphy et al., 2006).

The loss of stored information have been suggested to be one possible reason for impaired VF in AD, due to deteriorated semantic representations or the information linked to these (Burke et al., 1991; Burke & Shafto, 2004). Following, the deterioration of information stored in hierarchies in memory may also occur. This could result in not being able to access information, often at the higher levels in the hierarchy, such as *apple* in the larger *fruit* category (Beatty, Testa, English, & Winn, 1997). Henry, Crawford, and Phillips (2004) conducted a meta-analysis on studies to find support for the suggested discrepancy between types of VF tasks. They found support for this from estimated effect sizes based on large samples of AD patients and healthy controls. Hence, there may be more semantic memory impairments in AD, although the dissociation between phonemic and semantic VF has been noted to be exaggerated (Laws, Duncan, & Gale, 2010).

There has also been offered a possible moderating mechanism underlying the deficits in semantic memory impairment in AD, where processing speed plays the greater role (Rohrer, Salmon, Wixted, & Paulsen, 1999). Retrieval slowing will be less when words are related, compared to when they are not, but AD patients spend longer periods between each response even when words are associated (Holmen & Thorbjørnsen, 2013).

A third account for the VF impairment in early AD is executive dysfunction, where processes of selective search for responses, sustaining and monitoring in working memory, and inhibiting faulty responses are impaired (Collette, Van der Linden, & Salmon, 1999).

Clustering and Switching

To better understand the way in which word production occurs, the strategies of clustering and switching (Troyer et al., 1997) have been identified in several verbal fluency analyses. Clustering and switching are of great interest in the current study, and these measures will be presented in more depth. Subsequently, the use of clustering and switching used in VF performance in healthy ageing and in AD will be addressed.

Clustering and switching are strategies utilized by the participant during a VF task, which act to capture more information of VF performance beyond the traditional scoring procedures (Troyer et al., 1997). Whereas clustering and switching are thought to be utilised to the same extent in semantic VF, switching is suggested to play a bigger role in phonemic fluency (Ledoux et al., 2014).

Clustering. A cluster is a set of responses in succession that are of related lexical or semantic properties. In other words, sorting words into subcategories of relatedness is described as clustering. A phonemic cluster is a successive number of related words in response to letter stimuli (e.g. the letter *F*), and this type of cluster is defined by the way the word is structured. There are four types of phonemic clustering, based on whether words start with the two same letters (e.g. *father, family*), if words rhyme (*past, fast*), if the words are homonyms (*sun, son*), or if words differ only by one vowel (*cat, cut*). The words that are associated to one another belong in the one and same cluster, until responses do not fall within the current cluster. Then, a new cluster based on a different word structure may be generated.

A semantic cluster holds words in a successive order in response to a category stimulus, where relatedness is based on meaning. For instance, in the semantic VF task where the category is *animals*, words sharing properties of for instance natural habitat (e.g. African animals) would make up a cluster. For instance, if the words *zebra, giraffe, and gazelle* were given in succession

by the participant, these would be interpreted as one cluster. Similarly, the following words *beaver*, *guinea pig*, and *hamster* would all be exemplars within the cluster of rodents, where zoological properties are shared between the responses.

In order for clustering to take place, one relies on the capacity of retrieving related information from intact memory stores. Clustering has therefore also been suggested a sensitive index for memory capacity and the organization of stored information (Ledoux et al., 2014), and hence also temporal lobes function (Weakley & Schmitter-Edgecombe, 2014).

Switching. The act of transitioning between two clusters is called switching. This happens when the participant cannot retrieve any more words that fall within the current cluster, or if the word within one cluster also relates to another subcategory that initiates the start of another cluster. To illustrate, a phonemic switch would occur deliberately and controlled when available words starting with the same two words, such as *father*, and *family*, were exhausted, and a new approach to how the word is structured was applied. Thus, switching from words starting with *fa*, the participant may go on to words that rhyme, such as *fertility*, and *flexibility*, and so forth.

In semantic VF, switching would occur in the similar manner, when available words belonging to, for instance, the African animals cluster come to a halt, and the participant must think of another type of animal. If the next word that comes to mind is *beaver*, the likely succession of words would relate to animals in the rodent order. However, a switch may also apply if a word like *zebra* in the African animals cluster is followed by *horse*, which likely would activate a related word such as *mule* that initiates of a farm animals cluster.

Switching is a measure of how well the subject is able to selectively search for words relative to relatedness, and also to spontaneously change from one cluster to another. Hence, in order to manage this task, executive processes involving the shift of attention from one cluster to

another, which are connected to frontal lobe function (Weakley & Schmitter-Edgecombe, 2014), must be actively and effectively carried into effect.

Clustering and switching in normal ageing. In order for clustering and switching to be an efficient tool for identifying early AD, normative data for such must be addressed in healthy individuals differing in age. The little amount of research that addresses this notion varies in terms of how strategy use develops with age. Clustering does not seem to distinguish healthy groups of young and older people (Brucki & Rocha, 2004; Haugrud et al., 2010; Troyer, 2000), despite that some researchers have found age to correlate negatively with the number and size of clusters (McDowd et al., 2011; Wingfield & Kahana, 2002). Because clustering and switching together will produce the total number of correct words, there are reasons to suggest these are both impaired in elderly, as they produce fewer words than do younger adults. Perhaps unexpectedly, however, older adults have also been found to produce larger clusters than do younger adults (Troyer et al., 1997). This may be correlated to the increase in verbal knowledge with age, although there are also studies where such differences do not apply (Haugrud et al., 2010; Troyer et al., 2000).

The switching process also seems to decline in frequency and efficiency (Haugrud et al., 2010; Mayr & Kliegl, 2000), especially in the semantic VF task (Brucki & Rocha, 2004; March & Pattison, 2006; Troyer, 2000; 1997; Zhao et al., 2013). The reason for this may be the detriments of executive functions and processing speed that comes with increasing age (Salthouse, 1996). Others have found switching to increase with age (Ledoux et al., 2014), although associations were small, while others have revealed no effects on VF of ageing (Wilson, Evans, Emslie, Alderman, & Burgess, 1998).

Clustering and switching in early AD. Considering early AD in comparison to normal ageing, clustering and switching are less employed both in phonemic and semantic tasks (Beatty

et al., 1997; Gomez & White, 2006; Troyer, Moscovitch, Winocur, Leach, & Freedman, 1998; Tröster et al., 1998). However, the notion of an AD-specific impairment where clustering is poorer than switching has been suggested (Troyer, 2000). Clusters are fewer and smaller (Gomez & White, 2006; March & Pattison, 2006; McDowd et al., 2011), especially in semantic VF (Beatty et al., 1997; Murphy et al., 2006; Weakley & Schmitter-Edgecombe, 2014). This suggests a deficit in semantic memory capacity, as clustering depends mainly on the intact stores of information and their accessibility. Differences in cluster size have, however, also failed to appear between healthy elderly and patients with early AD (Bertola et al., 2014; Epker et al., 1999; Haugrud, Crossley, & Vrbancic, 2011).

Switching has been shown to be impaired in early AD, in line with executive dysfunction, but with uneven impact on the two different VF tasks. Some have found impaired switching in both semantic and phonemic VF (Beatty et al., 1997; Epker et al., 1999; Gomez & White, 2006; Weakley & Schmitter-Edgecombe, 2014), while others have only observed decline in the semantic task (Haugrud et al., 2011; Troyer et al., 1998). Remarkably, Raoux et al. (2008) found that the switching component predicted development of AD five years prior to diagnosis, which again highlights the importance of early identification of AD, and also the possibility of deficits beyond memory impairment.

Traditional Scoring Procedures

Research in VF has most often focused on quantification of the number of correct words produced, and intrusions and perseverations (collectively referred to as errors). These are the parameters usually considered in determining VF performance. Correct words are exemplars that belong within a given letter or category. The number of correct responses reflects the capacity and quality of memory stores, and the ability to retrieve information. Errors are related to executive dysfunction, and the failure of monitoring responses, and successfully inhibiting

unrelated words. One type of errors in phonemic VF, intrusions, includes words starting with a wrong letter, that are very similar to another response, or that end in the same way as another word. Semantic intrusions are words not corresponding to the category, or words that end the same way as another. Repetitions are perseverance of an aforementioned word in phonemic and semantic VF (Troyer et al., 1997).

Another measure, although not so often used in investigations of VF, is inter-item latency. Inter-item latencies reflect the speed of which one can process information, and how efficiently and rapid words are produced (Cerella, 1990). Based on these indices, investigators may interpret poor performance as a decline in memory capacity, executive dysfunction, and/or a slowing of processing speed, respectively. As such, traditional scoring methods provide quantitative indices of VF, while clustering and switching contribute with qualitative indices. Together, these may capture more information of VF performance than when only one of the two approaches is utilized.

Time-Course Analysis in VF

An approach of importance in the evaluation of VF performance is the time-course analysis. Little attention has been offered to the comparison of groups relative to their performance in the course of time. A time-course analysis of VF performance may not only reveal valuable information of cognitive development, but at which point in time processes are employed and when they seem to decline in function. The following sections will present what is known about VF performance in the course of time in normal ageing and in AD.

VF performance in relation to the first and last 30 seconds in normal ageing.

Researchers have pointed to a gradual decline in VF performance as a function of time (Fernaes & Almkvist, 1998), in which the number of correct words seems to level after about half the minute, and the frequency of words become smaller towards the end of the allocated time. Older

adults was found to produce fewer words than younger adults, but exhibited the similar pattern of more generated words in the first 30 seconds, followed by fewer generated words in the last 30 seconds (Zimmerman et al., 2014). Poorer performance in healthy elderly is thought to be partly mediated by impaired processing speed and executive dysfunction (Mayr & Kliegl, 2000). Clustering and switching should therefore also decline through the course of time, because the time it takes to retrieve an adequate response increases as time passes, and available words decrease as the degree of information available in memory gradually empty (Luo, Luk, & Bialystok, 2010). Raboutet et al. (2010), however, reported that cluster size actually increased during the last 30 seconds, in which clusters also consisted more of specific words and less of generic terms (e.g. seagull and pigeon instead of bird). Some authors point towards a decline in clustering and switching with age (McDowd et al., 2011), while other researchers have failed to find differences during the course of time between age-related groups (Brucki & Rocha, 2004).

VF performance in relation to the first and last 30 seconds in early AD. Considering the time-course component in relation to VF performance in AD patients, researchers adopted the methods forwarded by Fernaeus and Almkvist (1998). They found both healthy older adults and patients to show a general decline in the production of words throughout the minute (Holmen & Thorbjørnsen, 2013; Jones et al., 2006; Weakley & Schmitter-Edgecombe, 2014). In the more detailed time-course analysis by Holmen and Thorbjørnsen (2013; see also Rodriguez-Aranda, Holmen, Thorbjørnsen, Johnsen, & Waterloo, 2013), the minute was divided in periods of 10 seconds, and healthy older adults were compared to AD patients. Results revealed that AD patients were especially impaired in processing information rapidly as well as producing words during the first half of the minute, specifically in the semantic task. AD patients were distinguished from normal controls by a more gradual decline in VF responses. From this,

researchers suggested that the deficits may not follow a gradual pattern as in normal ageing, but rather point to a distinctive path of impairment.

When it comes to evaluations of clustering and switching, Weakley and Schmitter-Edgecombe (2014) have conducted one of few studies addressing clustering and switching in AD in relation to time. AD patients were outperformed by healthy elderly on the number of words and switching in both tasks, and in semantic cluster size. The authors therefore noted the possibility of impaired semantic memory function, and the ability to shift attention in AD patients. In relation to time, however, there were no differences found between healthy elderly and AD patients. Both groups exhibited the pattern expected in normal ageing, except for clustering, in which time did not affect performance in any of the investigated groups. The finding by Weakley and Schmitter-Edgecombe (2014) has also previously been reported (Jones et al., 2006), but only in terms of the number of correct words. Taken together, the studies investigating VF performance in time have pointed both to AD patients being impaired, but with varying findings regarding whether decline follows a normal or pathological path of execution through time.

Aim of the Current Study

Based on the previous work related to time-course analyses and VF, there are still some caveats that deserve attention. One of these refers to the evaluation of clustering and switching from a time-course perspective. By identifying eventual patterns of performance among various groups of elderly, it may be possible to better appraise the difficulties of, for instance AD patients, to achieve appropriate word production and retrieval. Some of the elements deciding VF performance have already been addressed, but there is a lack of studies investigating parameters of clustering and switching in young adults and elderly populations in terms of time.

To our knowledge, only one study (Weakley & Schmitter-Edgecombe, 2014) has addressed the question of clustering and switching in early AD relative to time. Thus, the present study will build on the studies by Holmen and Thorbjørnsen (2013) and Weakley and Schmitter-Edgecombe (2014). A time-course analysis approach will be employed to quantify standard measures (i.e. correct words, repetitions, intrusions, and inter-item latencies) and calculation of clustering and switching in two time periods. Moreover, the present study will include a young adult group for a more thorough account of age-related changes in the older adult group.

Thus, the aim of the present study is to conduct a time-course analysis of clustering and switching in phonemic and semantic VF among healthy young adults, healthy elderly, and patients at the early stages of AD. To begin with, the global results of all dependent measures based on analysis for one minute will be presented. Then, all parameters will be evaluated from a time-course perspective (i.e. by 30 second periods).

Hypotheses.

1. For the measurements of correct words, repetitions, and intrusions, it is expected that:
 - a. Healthy young adults will execute VF tasks at a higher level than older adults.
 - b. AD patients will produce fewer correct words and make more repetitions than the healthy groups in both tasks.
2. Clustering and switching are expected to be employed differently by young and older adults, and also differently by older adults compared to AD patients. Clustering is supposed to denote a strategy to produce related words, especially on the semantic VF. Hence, it is expected that clustering is dependent on enough and intact vocabulary knowledge, and temporal lobe integrity. In contrast, switching is more related to active processes of selection and adaptation that are thought to rely on executive

processes and frontal lobe functioning. Taking into account the above standpoints, the hypotheses regarding clustering and switching are as follows:

- a. The number of clusters is expected to be lower in older adults compared to young adults, while the size of clusters are likely to be greater in older adults. This is due to older adults potentially having greater vocabulary knowledge compared to young adults, as knowledge likely increase with age. However, because young adults often have higher education, there may not be group differences between the healthy groups. In healthy elderly, switching is expected to be lower in frequency compared to young adults, due to the slowing of efficient search and selection of words.
 - b. As for the AD group, these patients are expected to produce fewer clusters, and clusters of smaller size, compared to healthy older adults, especially on the semantic task. This is because of the deficits in semantic memory stores and retrieval capacity, likely due to the degenerative processes disrupting learned language information. For switching, AD patients are expected to be impaired to an exaggerated degree compared to healthy elderly.
3. In regards to the assessment of group performances on the first and last 30 second periods, it is expected that:
- a. Both young and older adults display a greater number of words during the first time period (i.e. 0-30 seconds). Repetitions and intrusions may not differ in terms of time. Inter-item latencies, however, are expected to be of longer duration in older adults compared to young adults. However, the same pattern of the usage of intervals is expected through time as for the number of correct words.

- b. AD patients may produce fewer correct words through time, especially in semantic VF. Repetitions increase through time, while intrusions may occur in an uneven manner throughout the allocated time. Inter-item latencies are longer in duration compared to older adults, especially in semantic VF.
4. Considering the question of greatest interest and focus in this study, namely clustering and switching in the course of time, expectations involve that:
 - a. Both young and older adults display a greater number of clusters and switches during the first time period (i.e. 0-30 seconds) than the second time period (i.e. 31-60 seconds). Cluster size should not change over time.
 - b. Regarding the AD patients, it is difficult to be certain of what their performance should be, due to the lack of earlier research. However, based on previous studies in Tromsø, AD patients should not show change through time regarding reduced number and size of clusters, as compared to the healthy elderly group. It is expected that impaired switching will occur in an uneven manner throughout the allocated time.

Operationalization. A phonemic cluster will be accounted when a set of words are related in terms of structure given in succession in response to a phonemic stimulus, such as the letter *F*. A set of words make up a cluster if words start with the two same letters, if words rhyme, are homonyms, or if words differ only by one vowel. A semantic cluster will be accounted when words in a successive order that shares meaning in response to a semantic stimulus, such as the category *animals*, are produced. A cluster applies when words share properties of class or order, natural habitat, or zoology, and so forth.

Cluster size is the number of words within a cluster, where the words are related either in terms of meaning (as for semantic clustering) or by lexical properties (in phonemic clustering).

The size of a cluster will be the total number of words minus one.

Switching is the act of transitioning from one subcategory to another. A phonemic switch would mean transitioning from one cluster based on, for instance, the two same first letters, to another cluster, where words are related because they rhyme with one another. A semantic switch would mean going from one cluster based on, for example, natural habitat, to another, such as zoological properties.

The above quantifications will be performed on the first 30 seconds and the last 30 seconds of each VF stimulus. Equally, the inter-item latencies will be accounted to appraise the speed of information processing relative to clustering and switching.

Method

Participants

In this study, a total of 66 adult participants (31 females) were divided into three groups, of whom 24 (13 females) were healthy young adults (mean age 30.2), 23 (9 females) were healthy older adults (mean age 67.0), and 19 (9 females; mean age 64.1) were diagnosed with early AD.

Participants were recruited through the Institute of Psychology at the University of Tromsø (UiT), in cooperation with the University Hospital of North Norway (UNN). Healthy young participants were all students at the University of Tromsø. Welfare centres for the elderly were contacted, and healthy older adults from previous studies were also invited to participate in the study. Patients with early AD were recruited from the geriatric/neurology ward at UNN. Participants were all from Northern Norway, and had Norwegian as their first language, except for one participant in the healthy older adults group, who was of Swedish origin. Responses were nevertheless readily understandable, and the participant was therefore included in the study.

Participants were all interviewed regarding demographic and health related background. Those holding a history of alcohol and/or drug abuse, psychiatric or neurological problems, or who were treated with and potentially under the influence of psychopharmacological medicine were excluded from the study. Participants were assessed for dementia through the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975), and depression using Beck Depression Inventory (BDI; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961). Healthy older adults scoring within the range of 0 and 18 on the BDI were included in the study, although the upper score reflect mild depression. This was done due to that some of the aspects of depression are expected to follow ageing alone, such as sleep and appetite changes (Rodríguez-Aranda, 2003). Age, sex, years of education, and word comprehension was noted and assessed for each participant across groups.

For the patient group, older adults with probable AD determined by the MMSE score between 19 and 24 were further referred to and examined by a neurologist or a geriatrist at UNN. The diagnosis of early AD have later been confirmed at one year follow-up, confirming that the participants included in the patient group was in the early stage of the disease during which the experiment took place. The study has been accepted by the Regional Committees for Medical and Health Research Ethics (REK) for North Norway.

Materials

Assessments included the phonemic (Benton, 1968) and semantic (Newcombe, 1969) VF tests. Testing was assessed, performed, and analyzed in Norwegian language.

Phonemic fluency tests. Phonemic stimuli in the forms of the letters *F*, *A*, and *S* were shown on a computer screen following instructions and an example. The participant was informed about what the general goal was (to produce as many words as possible relative to the stimulus), what words should be avoided (proper nouns, repetitions, and very similar words).

Each letter shown on the screen remained for one minute following a sound signal. Thereafter a new letter appeared for one minute.

Semantic fluency tests. The categories *animals*, *fruit and vegetables*, and *professions* were utilized as the three stimuli for the semantic VF task. The test followed the same principles as for the phonemic fluency test, and instructions and an example were given before the first stimulus was shown to the subject, each for one minute.

Procedure

Participants were informed about the study, both orally and in written, and about their rights as participants in the study. Informed consent was obtained after giving participants the possibility of asking questions, before running the health-related background interview previously mentioned. Demographic data including sex, age, and education was collected, in addition to scores of vocabulary, BDI, and MMSE. VF testing took place in an isolated setting, in a room where the participant was assessed by an experimenter employed at University of Tromsø.

Spectrographic analyses. Seated approximately 50 cm away from a 15 inch sized screen, participants were asked to wear headphones equipped with a microphone for the recording of responses. Stimuli were presented following a sound signal (beep) through the software E-prime. First, the phonemic task was presented, followed by the semantic task. This order of test administration was applied to all participants across groups.

Verbal fluency output was recorded, transcribed, and analysed using the CSL 4500 (KayPENTAX, Lincoln Park, NJ) computer software. By the aid of soundwave oscillations, measurements of the total number of responses, correct words produced, intrusions, repetitions, clusters, cluster size, number of switches, and inter-item latencies (the duration between each spoken word) were calculated manually for each participant. The duration of each word produced

was not accounted for, due to a large variability in the dialect between participants. Also, the reaction time was not included in the analyses.

Calculation of VF scores. Where provided, examples of VF responses are presented with the original Norwegian response italicized, followed by the English translation put in brackets.

Correct words. Responses corresponding to the phonemic or semantic stimulus requirement were scored as correct responses.

Slang and words that are not originally Norwegian, but that still are considered part of everyday speech (e.g. *spray*, *aftershave*), pet names (*pusi* [*pussycat*]), and words of dialectic variance (*anna/annet* [*other*]) was accepted as correct responses. This was also the case for homophonic words if the participant explained the difference between them (*frank* [*free*] and *Frank*, as the name *Frank*).

Errors. Two types of errors include intrusions and repetitions. These were calculated as explained below.

Intrusions. Phonemic intrusions corresponded to words that start with a letter not presented at the screen, proper nouns (e.g. the country *Finland*, or the name *Frank*), and words that only differed in their ending (*fiskestang* [*fishing rod*], *fiskebåt* [*fishing boat*]). Semantic intrusions were words not belonging to the given category.

Repetitions. Exact words previously generated were scored as repetitions.

General responses followed by specific responses. In some cases, participants produced words belonging to a general concept anteceding a more specific exemplar (e.g. *fugl* [*bird*], followed by *kråke* [*crow*]). The latter, more specific response was counted as a correct response, while the more general word (*fugl*) was not scored. It was simply left out when calculating the number of correct responses.

Clustering. To calculate clusters, the framework suggested by Troyer et al. (1997) was adopted in the present study, with a degree of amendment. The number of clusters was scored with intrusions, repetitions, and also the general responses (antedecedent by specific exemplars) included. This is due to how clustering and switching may reflect ways of thinking and sorting information relative to relatedness. In this case, errors could contribute to an enhanced understanding of how one may use clustering and switching in VF, irrespective of whether the response is correct or not.

Phonemic clustering. For phonemic VF, words were clustered if they started with the two same letters (e.g. *far* [father], *for* [for]), if words rhymed (*fortid* [past], *framtid* [future]), were homonyms (*skjære* [magpie], *skjære* [to carve]), or if words differed only by one vowel (*fisk* [fish], *fusk* [cheating]). In some cases, a more flexible scoring method was employed. For instance, two more specific clusters were merged into one more general where possible. For example, *friksjon* [friction] and *frø* [seed]) belong to one cluster where responses share the first two letters, while *fryse* [to freeze] and *frese* [to hiss] belong to another cluster based on that words rhyme. However, because all four responses share the first two letters, they were merged into the one and same cluster.

Semantic clustering. Semantic VF clustering depends more on meaning. For the animal category, a cluster would therefore be defined by factors like natural habitat, human use, or zoological characterisation. A cluster could consist of *sebra* [zebra], *elefant* [elephant], and *løve* [lion], all characterized by their African habitat, for instance. As in phonemic VF scoring, a flexible scoring approach was used in some cases. In the case where one word did belong to two adjacent clusters, it was considered to belong to both of them. For instance, the word *pelican* would be assigned both to *African animals* and *birds* if these happened to be neighbouring semantic clusters.

Fruits and vegetables category clusters were defined relative to the more general division of fruits and vegetables. This is due to the variable way of thinking about and mentally organizing fruits and vegetables. Some may relate to their association to items bought at the store, while others categorize different items depending on their botanical definition, or even by their color or shape. Included, however, was the subcategory *berries*, due to responses relative to this category were almost always given in a successive manner.

For the profession category, the relation between words was more readily clustered based on the nature of the profession and to which sector, service, or hierarchical level the response belongs. For instance, *tannlege* [*dentist*] and *kirurg* [*surgeon*] share properties that make them subcategories of the same category.

Cluster size. Following Troyer et al. (1997), each cluster was calculated for size by subtracting one word from the total number of correct responses. This is the most common way of deciding the size, although some researchers have used the minimum of three words in order to call a set of words a cluster (Carmo, Duarte, Pinho, Marques, & Filipe, 2015). The more common way of calculating cluster size (i.e. total number minus one) has not been addressed as to why a cluster size is calculated exactly this way. It is probably done this way because the first word given represents the subcategory itself (such as the word *cat* represents the zoological subcategory *feline*, and the next words *cheetah* and *puma* count as exemplars within this subcategory). Hence, the cluster size of three consecutive words (*cat*, *cheetah*, and *puma*) will be three minus one (*cat*) giving a size of two.

This way of calculating cluster size also included intrusions, repetitions, and general words followed by specific exemplars. Single words were following not considered clusters.

Switching. For both VF tests the number of switches was calculated for each of the stimuli by counting every shift from one cluster (or single word not related to the previous or following response) to another.

Inter-item latencies. The duration between each spoken word was also noted for each stimulus. This was done by measuring the time between the point at which one word stopped and the other started, aided both by auditory and visual cues through the spectrographic software CSL 4500. The duration was accurately noted as displayed in the program.

Scoring related to interval analyses. To better comprehend the nature of verbal fluency impairment in early AD, all VF parameters were evaluated relative to the whole minute allocated for each VF test stimuli. In addition, the assessment was also performed for the first 30 seconds and the last 30 seconds of each trial. The latter approach led to a somewhat dynamic scoring procedure of clustering and switching:

Clustering relative to time-course analyses. When a cluster was situated in between the division of the two time periods (0-30 and 31-60 seconds), the cluster was attributed to both the first and last 30 seconds.

Mean cluster size relative to time-course analyses. When a cluster was situated in both the first and last 30 seconds, the cluster size was calculated as if the cluster belonged exclusively to both of the intervals.

Switching relative to time-course analyses. When scoring the number of switches, a switch situated in between the two time periods was considered to belong to the first interval to which the switch was initiated.

Statistical analyses. Analyses were performed using the statistical software SPSS 22.0.0. To assess differences between groups relative to the minute as a whole, a one-way analysis of variance (ANOVA) was conducted. Following, to reveal potential differences between groups

relative to the first and last 30 seconds, a set of 2 X 3 multivariate analysis of variance (MANOVA) with repeated measures in one factor was employed, for phonemic and semantic VF. Group served as the between-groups factor and time period as the within-groups factor. Additional post hoc analyses and pairwise comparisons were performed in order to know between which groups and in what time period(s) the significant differences existed.

Because vocabulary is an important mediator of VF, it was decided to control for this variable by conducting a set of multivariate analysis of covariance (MANCOVA) after the series of MANOVAs.

Results

Results will be presented in the following manner: First, demographic and cognitive variables describing the samples. Second, group contrasts for all VF parameters relative to the whole minute. Third, group contrasts for all VF parameters relative to the first 30 seconds and the last 30 seconds, and fourth, significant group differences after controlling for vocabulary. Demographic and cognitive information is presented for the three groups in Table 1. Only one participant in the healthy older adults group had missing data for word comprehension.

Results showed significant group differences in years of education, $F(2, 63) = 19.09, p < .001$. Older individuals and patients with early AD were equal on education, while young adults had more years in education (both $p < .001$). As expected, MMSE differed significantly between groups, $F(2, 63) = 24.15, p < .001$. Young and older adults scored comparably, and did better than AD patients (both $p < .001$). Regarding vocabulary performance, differences were found, $F(2, 62) = 5.14, p < .009$. The young group scored higher than patients ($p = .006$), but did not differ from healthy elderly.

Table 1

Demographic and Cognitive Information by Group

	Young adults (<i>n</i> = 24)		Older adults (<i>n</i> = 22)		AD patients (<i>n</i> = 19)	
	13/1		9/14		9/10	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Gender ratio (females/males)						
Age ***	30.17	5.90	67.00	8.22	64.05	10.08
Education in years ***	17.08	3.23	12.13	3.76	11.00	3.53
Vocabulary score **	52.67	10.63	46.64	15.32	40.16	11.80
MMSE ***	28.79	1.18	28.74	0.69	25.00	3.40

Note. Groups are significantly different in age, education, vocabulary, and MMSE.

** $p < .01$. *** $p < .001$.

VF Performance Relative to the Whole Minute

Phonemic VF performance in normal ageing and early AD. No differences were revealed between the healthy control groups. In comparing controls and AD patients, however, differences were found between groups in correct responses, $F(2, 63) = 8.77, p < .001$ (see Figure 1). Post-hoc Tukey HSD revealed that AD patients produced fewer words than young adults ($p < .001$), and also fewer words compared to older adults ($p = .012$). The number of clusters was also different between groups, $F(2, 63) = 7.60, p = .001$. The AD group produced fewer clusters than young adults ($p = .001$), and also compared to healthy older adults ($p = .042$). The size of clusters and switching did not differ significantly between AD patients and the control groups.

Differences were also found in the number of repetitions, $F(2, 63) = 9.26, p < .001$ (see Figure 2).

The AD group repeated words more than young adults ($p < .001$), and also compared to healthy

older adults, although this latter difference was at the limit of significance ($p = .047$). The differences in intrusions were not significantly different between healthy elderly and AD patients.

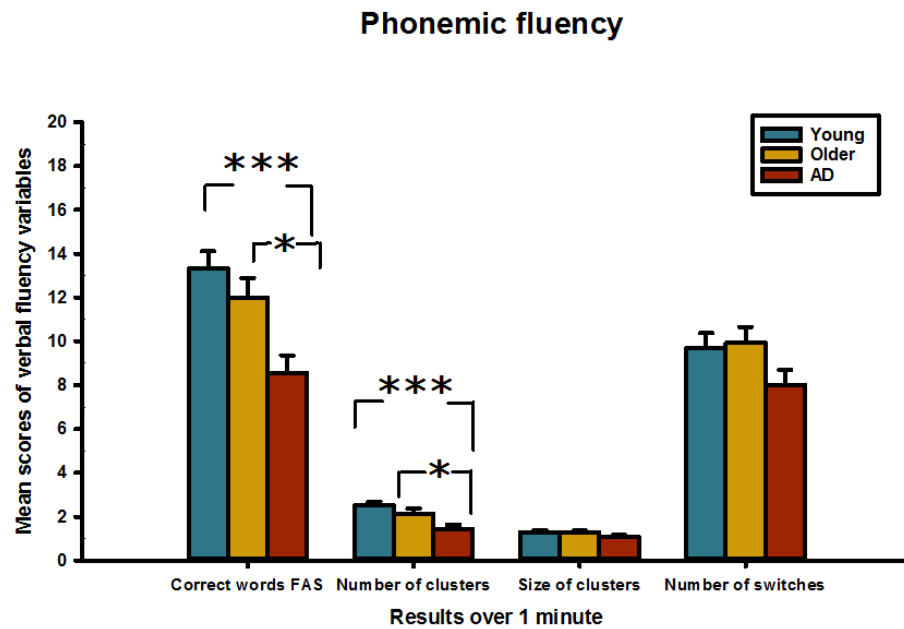


Figure 1. Mean scores for phonemic VF parameters by group.

* $p < .05$. *** $p < .001$.

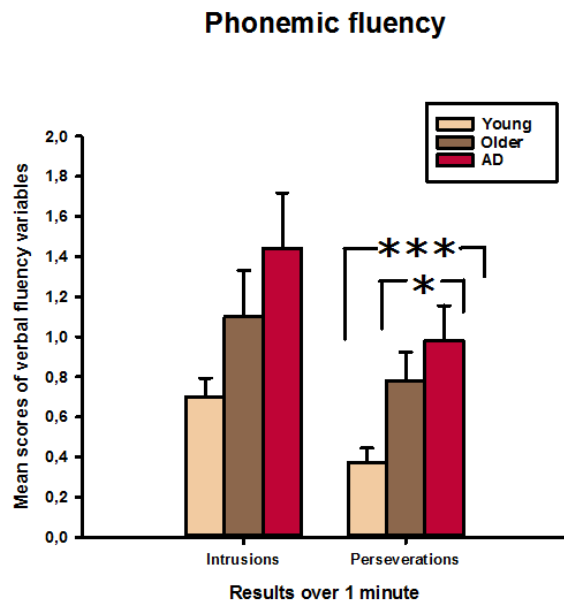


Figure 2. Mean scores for phonemic VF parameters by group.

* $p < .05$. ** $p < .01$.

Semantic VF performance in normal ageing and early AD. Results revealed significant differences between young and older adults related to the number of clusters, and the frequency of switching. Older adults produced fewer clusters ($p = .021$), and switched less frequently than young adults ($p = .015$). The AD group also differed significantly from controls on the number of correct words, $F(2, 62) = 19.68, p < .001$. Post-hoc Tukey HSD revealed that the AD group produced fewer words than young and older adults (both $p < .001$; see Figure 3). Considering the number of clusters, a difference was statistically significant, $F(2, 62) = 12.62, p < .001$. AD patients produced fewer clusters compared to young ($p < .001$) and older adults ($p = .049$). For switching, the difference between groups did also reach significance, $F(2, 62) = 16.24, p < .001$. AD patients switched less than both young ($p < .001$) and older adults ($p = .012$). Cluster size did not differ significantly between groups.

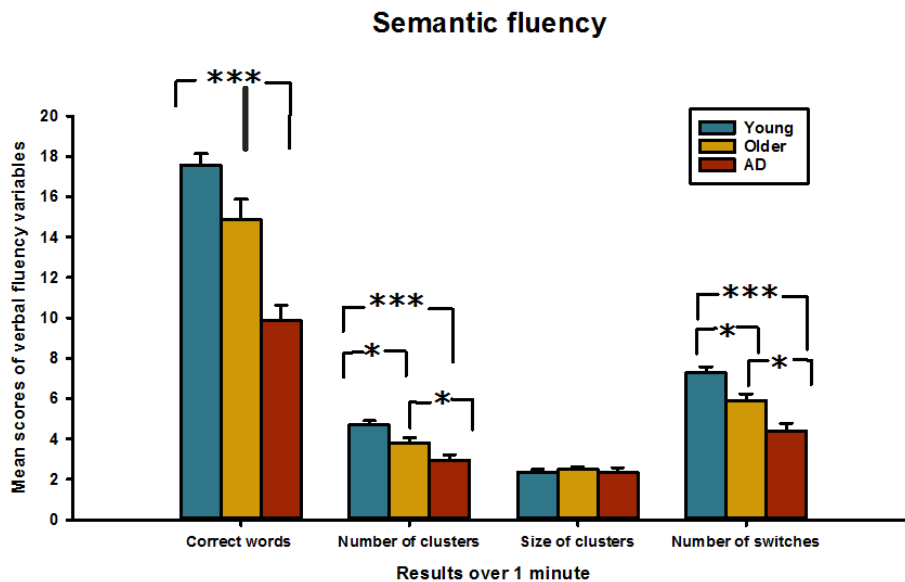


Figure 3. Mean scores for semantic VF parameters by group.

* $p < .05$. *** $p < .001$.

Regarding repetitions, differences also applied, $F(2, 62) = 7.24, p = .001$ (see Figure 4). AD patients made more repetitions than young adults ($p = .002$), and also more than older adults ($p = .012$). Statistically significant differences failed to appear in the number of intrusions.

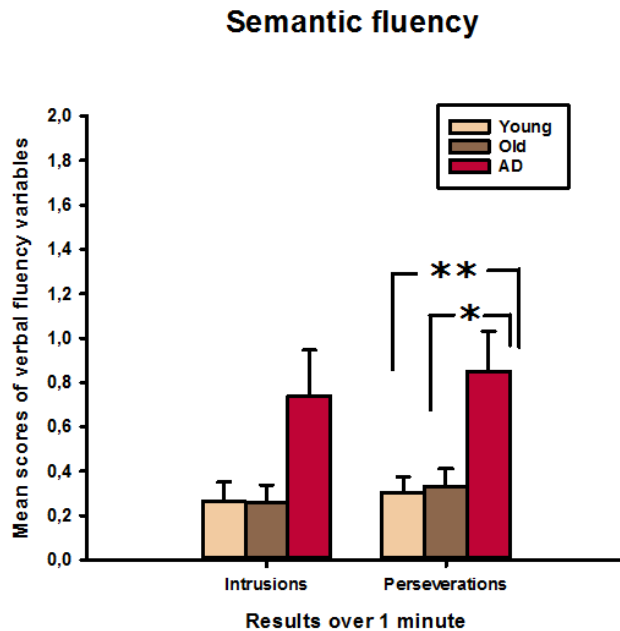


Figure 4. Mean scores for semantic VF parameters by group.

* $p < .05$. ** $p < .01$.

VF Performance Relative to the First 30 Seconds and the Last 30 Seconds

For the inter-item latencies, raw mean scores were transformed to standardized Z-scores which is a regular procedure for these data. Some data were missing. For the phonemic VF analyses, a total of 24 healthy young adults, 22 healthy older adults, and 19 AD patients were included. For the semantic VF analyses, the same number of healthy participants applied, whereas 13 AD patients were included.

Phonemic VF. Results revealed a main effect of group, $F(14, 114) = 4.88, p < .001$, and period of time (the first 30 seconds and the last 30 seconds), $F(7, 56) = 21.87, p < .001$.

Univariate analyses showed significant differences between groups in the number of correct words, $F(2, 62) = 4.84, p = .011$, repetitions, $F(2, 62) = 20.38, p < .001$, intrusions, $F(2, 62) = 10.69, p < .001$, the number of clusters, $F(2, 62) = 7.31, p < .001$, and the inter-item latencies, $F(2, 62) = 3.28, p = .049$. Results showed significant differences between the first and last 30 seconds in the number of correct words, $F(1, 62) = 112.41, p < .001$, repetitions, $F(1, 62) = 37.51, p < .001$, the number of clusters, $F(1, 62) = 35.04, p < .001$, cluster size, $F(1, 62) = 4.03, p = .049$, and the inter-item latencies, $F(1, 62) = 11.78, p = .001$. Moreover, a significant interaction effect was revealed for group and time, $F(14, 114) = 3.42, p < .001$. This applied to the number of repetitions, $F(2, 62) = 14.65, p < .001$, and the frequency of switching, $F(2, 62) = 4.65, p = .013$.

Pairwise comparison analyses of phonemic VF in normal ageing and early AD.

Performance scores for all groups are presented in Table 2. Pairwise comparisons delineated in which groups and in which time period these differences existed. Young and older adults performed very similarly in phonemic VF, with no other differences appearing between groups apart from higher rates of errors in the older group. In both the first 30 seconds ($p = 0.012$) and the last 30 seconds ($p = .018$), older adults repeated words more often than young adults. The similar finding applied to intrusions, in which older adults produced more intrusions both in the first ($p = .020$) and last ($p < .001$) 30 seconds compared to the young group.

Considering early AD patients in relation to controls, differences in phonemic VF were more readily observed. Regarding the number of correct words, AD patients produced fewer words than did young adults ($p = .007$), and also fewer than older adults ($p = .046$), but only for the first half of the minute (see Figure 5). For repetitions in phonemic VF, AD patients repeated words more frequently than young ($p = .001$) and older adults ($p < .001$) during the last 30

seconds (see Figure 6). Regarding intrusions, AD patients produced more faulty words than young adults in the first ($p = .003$) and last ($p = .001$) 30 seconds (see Figure 7).

Table 2

Phonemic VF Scores for Young Adults, Older Adults, and Early AD Patients in the First and Last 30 Seconds

		0-30 seconds		31-60 seconds	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Correct words	Young	8.9	2.49	5.74	2.39
	Older	8.44	2.58	5.58	2.05
	AD	6.56	2.09	4.37	1.94
Repeated words	Young	0.1	0.18	0.29	0.36
	Older	0.73	0.88	1.23	1.27
	AD	0.47	0.9	2.63	1.5
Intrusions	Young	0.39	0.34	0.32	0.32
	Older	2.02	2.39	1.89	1.62
	AD	2.45	2.55	1.82	1.63
Number of clusters	Young	1.72	0.8	1.03	0.4
	Older	1.29	0.81	1.02	0.54
	AD	0.98	0.57	0.54	0.37
Cluster size	Young	1.28	0.68	1.16	0.77
	Older	1.05	0.57	0.93	0.47
	AD	1.04	0.61	0.78	0.51
Number of switches	Young	6.19	2.22	3.51	1.55
	Older	5.97	2.54	3.86	1.45
	AD	4.3	1.91	3.4	1.67
Inter-item latencies	Young	0.02	0.38	0.15	0.33
	Older	-0.03	0.7	0.39	0.49
	AD	0.35	0.7	0.49	0.43

Note. M = Mean; SD = Standard deviation. Inter-item latencies are displayed as mean Z-scores.

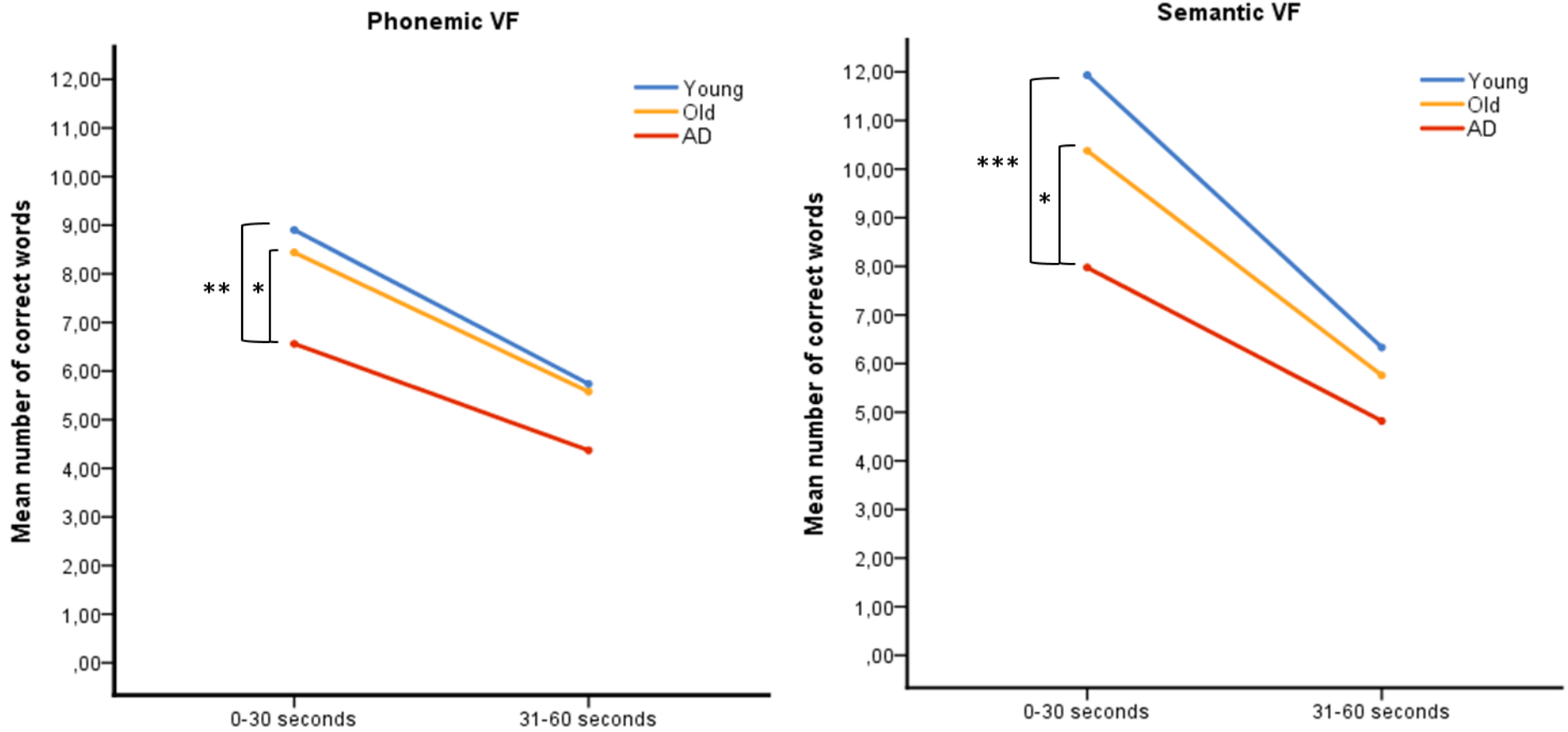


Figure 5. Mean number of correct words by group and time period.

* $p < .05$. ** $p < .01$. *** $p < .001$.

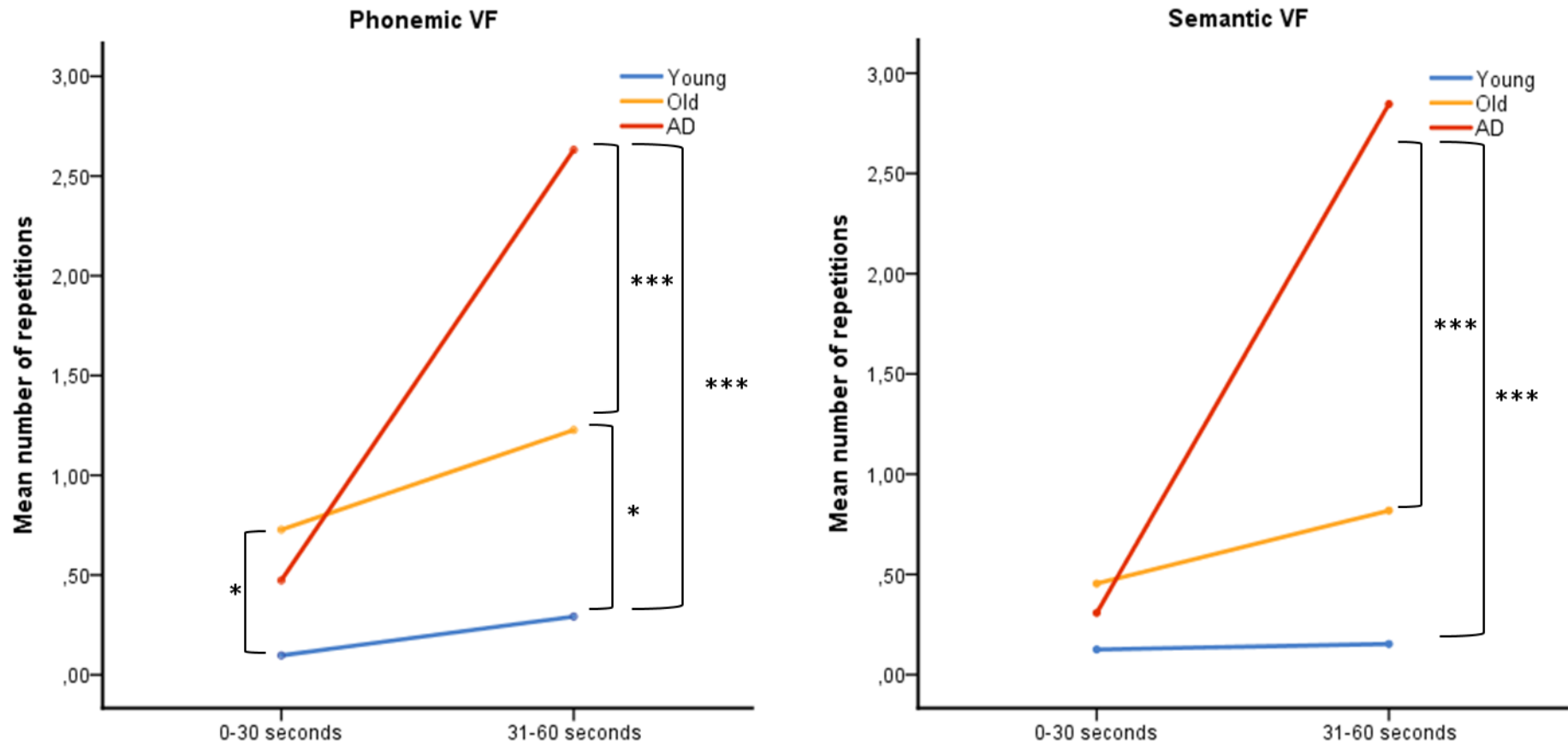


Figure 6. Mean number of repetitions by group and time period.

* $p < .05$. *** $p < .001$.

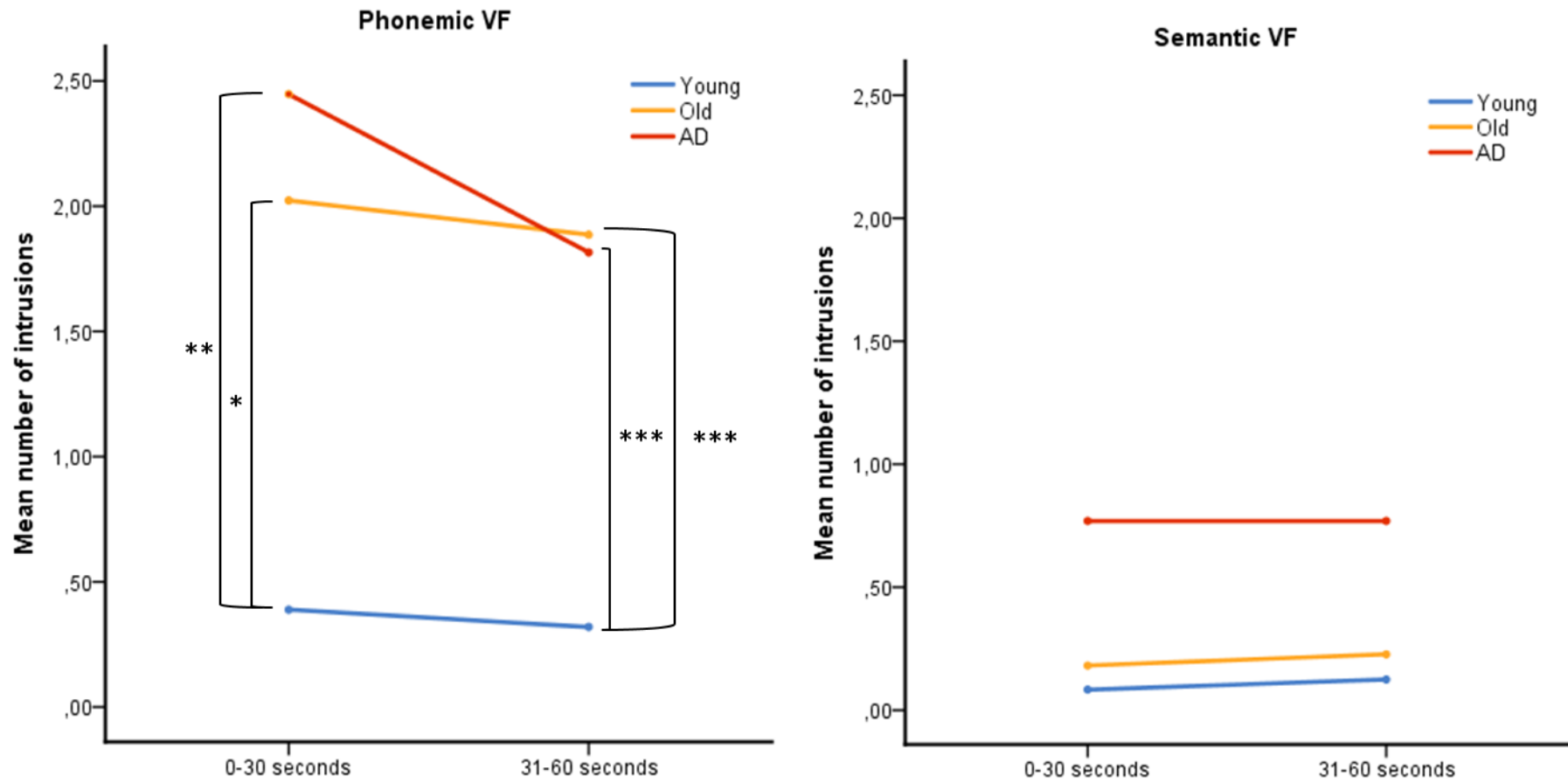


Figure 7. Mean number of intrusions by group and time period.

* $p < .05$. ** $p < .01$. *** $p < .001$.

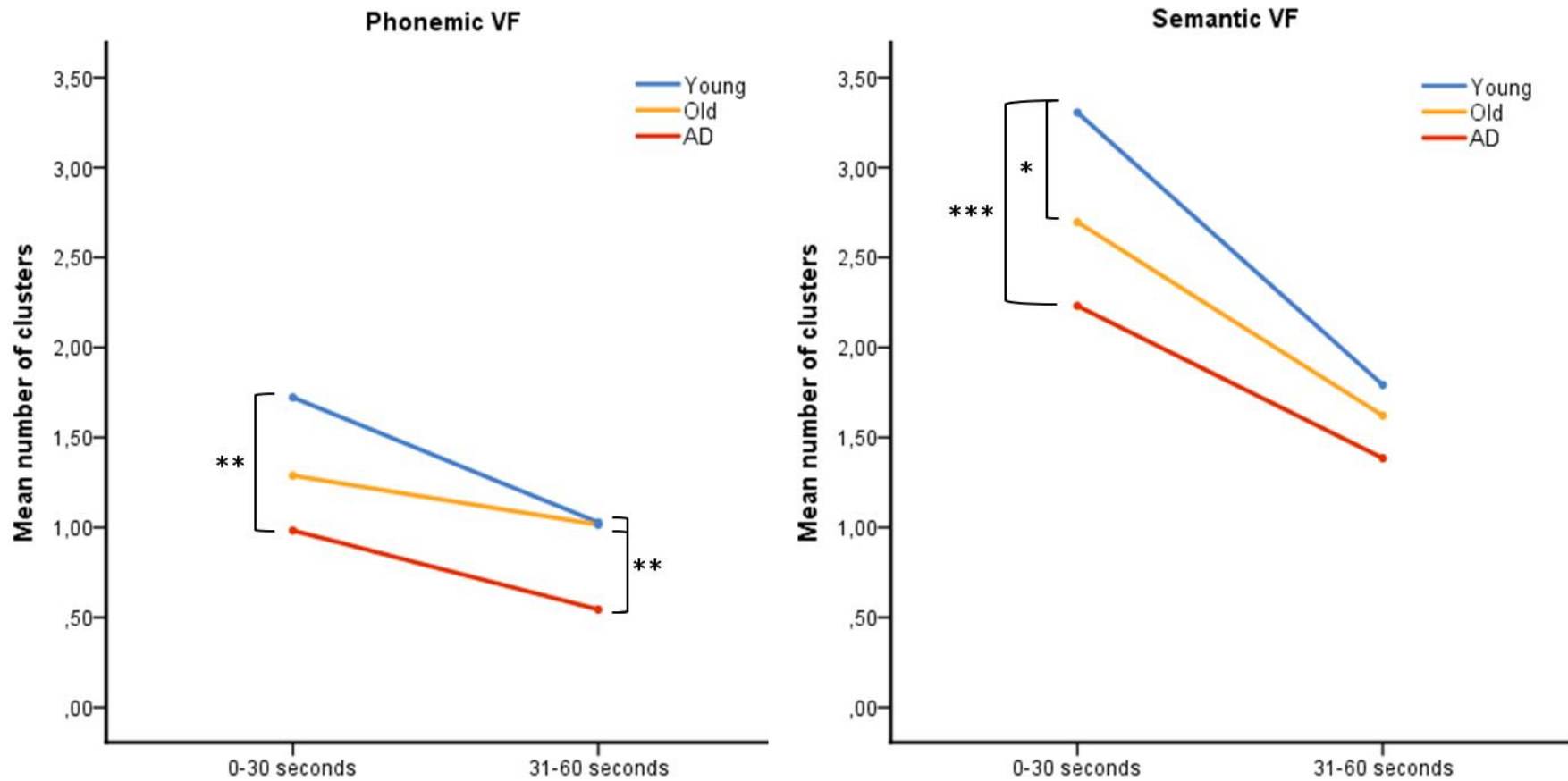


Figure 8. Mean number of clusters by group and time period.

* $p < .05$. ** $p < .01$. *** $p < .001$.

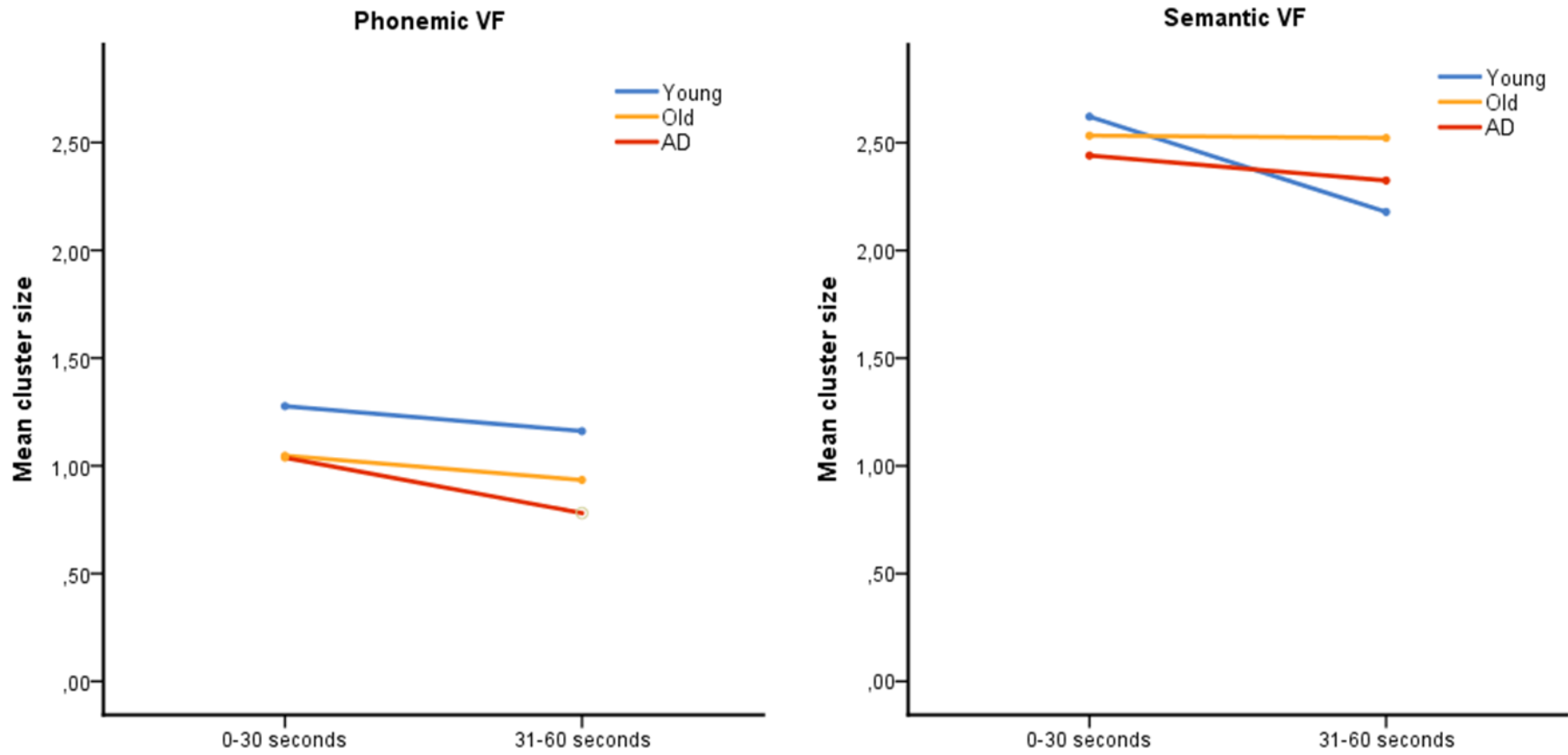


Figure 9. Mean size of clusters by group and time period.

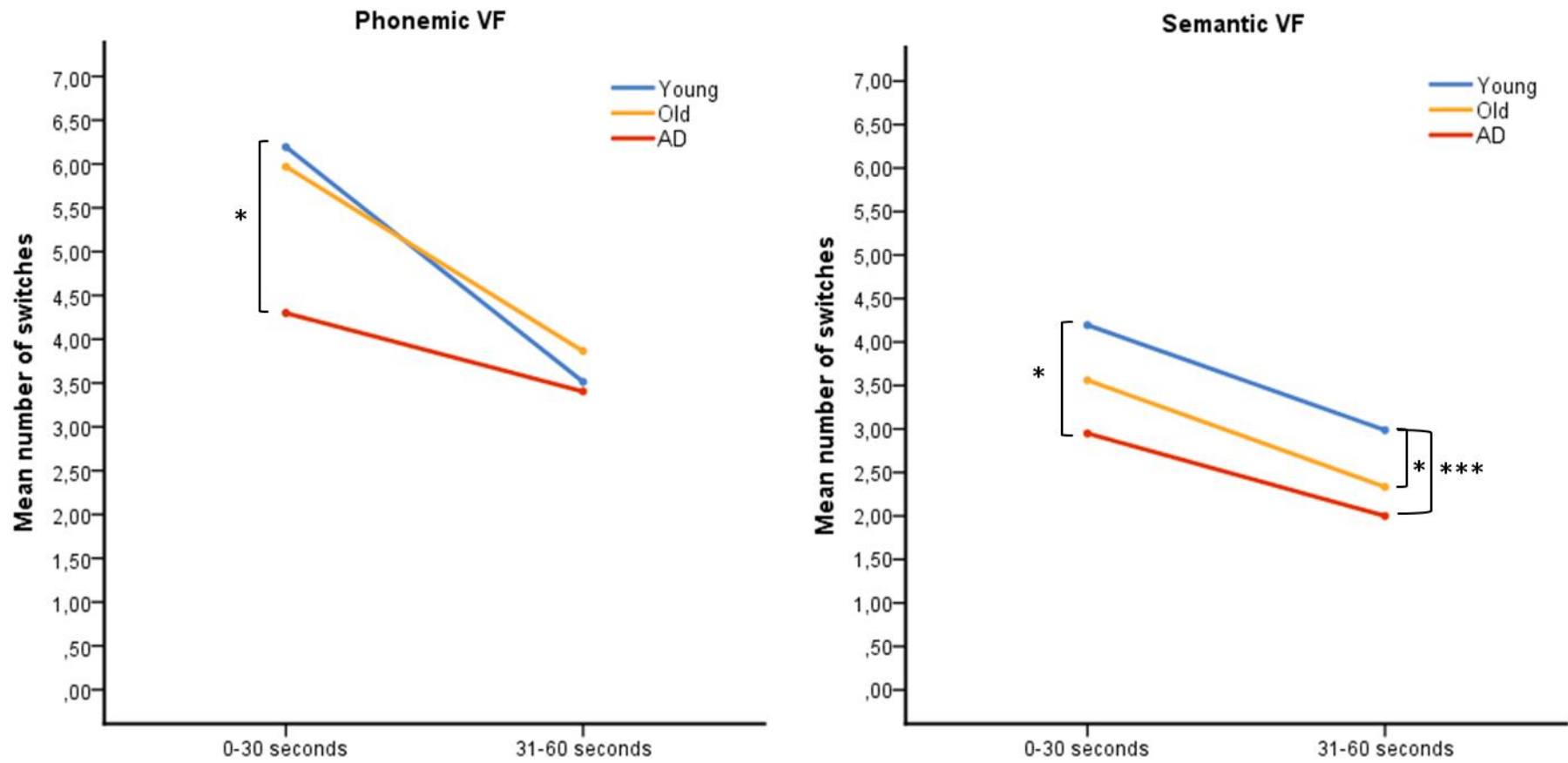


Figure 10. Mean number switches by group and time period.

* $p < .05$. *** $p < .001$.

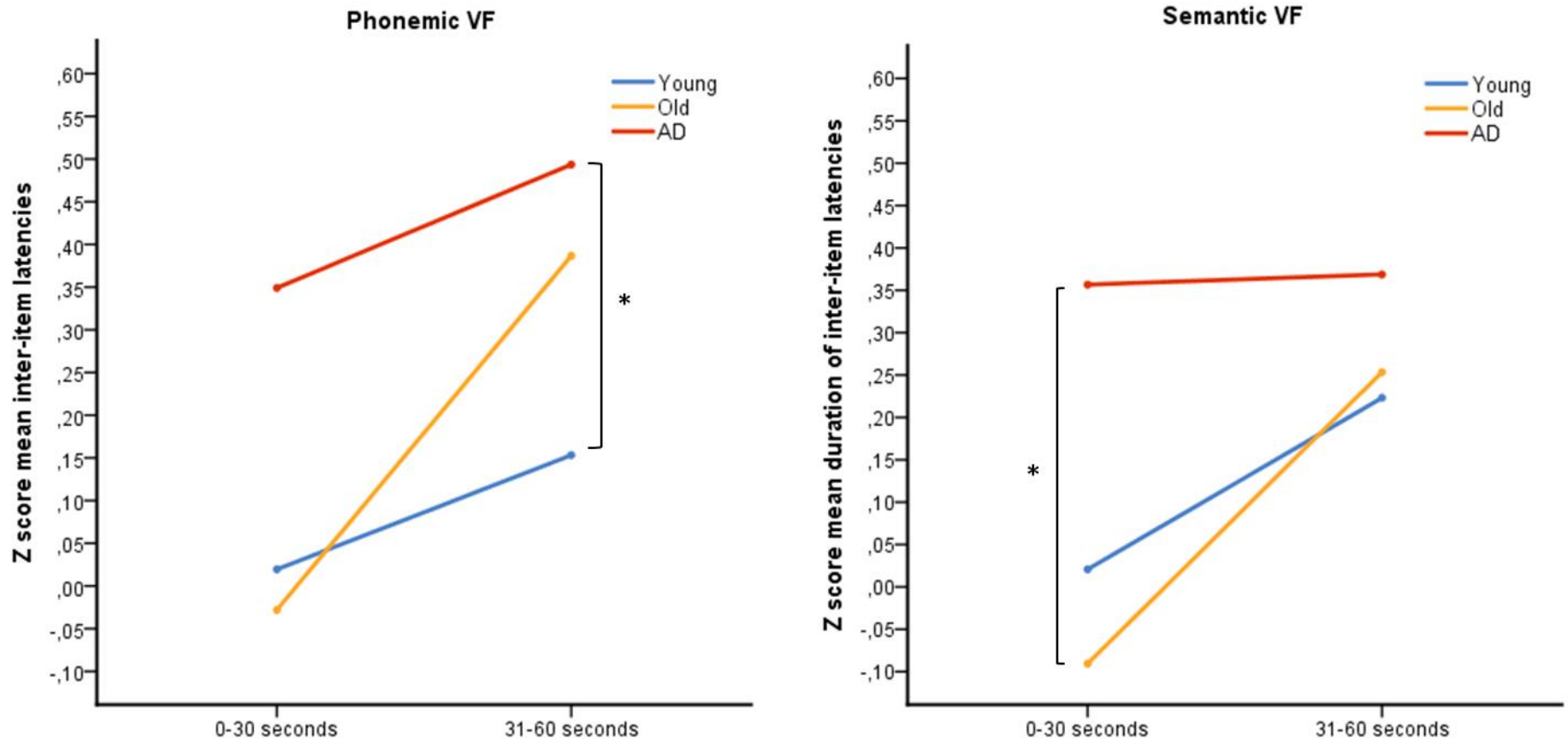


Figure 11. Z score mean duration of inter-item latencies by group and time period.

* $p < .05$.

In phonemic VF, the number of clusters was lower for AD patients than young adults ($p = .006$) in the first 30 seconds. This was also the case in the last 30 seconds ($p = .002$). The AD group also produced fewer clusters than older adults ($p = .004$) in the second half of the minute (see Figure 8). The size of clusters did not differ between groups (see Figure 9). Switches were less frequent for AD patients compared to young adults, but only in the first half of the minute ($p = .024$; see Figure 10). Inter-item latencies differed between groups only in the last 30 seconds, as AD patients exhibited longer latencies than young adults ($p = .030$; see Figure 11).

Semantic VF. Results revealed a main effect of group, $F(14, 102) = 4.88, p < .001$, and period of time, $F(7, 50) = 64.08, p < .001$. Univariate analyses showed significant differences in the number of correct words, $F(2, 56) = 8.24, p = .001$, repetitions, $F(2, 56) = 17.17, p < .001$, intrusions, $F(2, 56) = 3.81, p < .028$, the number of clusters, $F(2, 56) = 7.29, p = .002$, and in the number of switches, $F(2, 56) = 9.33, p < .001$. Univariate analyses also showed significant differences between time periods in the number of clusters, $F(1, 56) = 98.27, p < .001$, switching, $F(1, 56) = 36.56, p < .001$, and inter-item latencies, $F(1, 56) = 9.92, p = .003$. There was in addition a significant interaction for group and time, $F(14, 102) = 3.68, p < .001$. Interaction effects were found for the number of correct words, $F(2, 56) = 4.52, p = .015$, and frequency of repetitions, $F(2, 56) = 25.20, p < .001$.

Pairwise comparison analyses of semantic VF in normal ageing and early AD.

Performance scores are presented in Table 3. By using pairwise comparisons, results revealed that young and older adults differed in terms of the number of clusters, and in the number of switches. Older adults produced fewer clusters in the first 30 seconds ($p = .036$), and both groups exhibited less clustering in the last 30 seconds. Regarding switching, older adults switched less frequently during the latter part of the minute, compared to young adults ($p = .013$).

When it comes to the AD group, patients produced fewer words than older adults ($p = .029$), but only in the first 30 seconds (see Figure 5). Patients with AD also repeated words more often than older adults ($p < .001$), but only in the last 30 seconds (see Figure 6). For the number of clusters no differences applied between AD patients and older adults (see Figure 8). AD did not differ from older adults in switching (see Figure 10). Inter-item latencies were of longer duration for the AD group compared to older adults ($p = .014$), but only for the first 30 seconds (see Figure 11). There were no significant differences in the rate of intrusions (see Figure 7) or in the size of clusters (see Figure 9).

Table 3

Semantic VF Scores for Young Adults, Older Adults, and Early AD Patients in the First and Last 30 Seconds

		0-30 seconds		31-60 seconds	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Correct words	Young	11.93	2.25	6.33	1.52
	Older	10.38	2.91	5.76	2.56
	AD	7.97	2.51	4.82	1.45
Repeated words	Young	0.13	0.16	0.15	0.2
	Older	0.45	0.74	0.82	1.3
	AD	0.31	0.48	2.85	1.77
Intrusions	Young	0.08	0.18	0.13	0.26
	Older	0.18	0.5	0.23	0.43
	AD	0.77	1.69	0.77	1.74
Number of clusters	Young	3.31	0.77	1.79	0.58
	Older	2.7	0.84	1.62	0.77
	AD	2.23	0.77	1.38	0.43
Cluster size	Young	2.62	0.98	2.18	0.83
	Older	2.53	0.79	2.52	1.04
	AD	2.44	1.14	2.32	1.18

		0-30 seconds		31-60 seconds	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Number of switches	Young	4.19	1.3	2.99	0.83
	Older	3.56	1.35	2.33	0.65
	AD	2.95	1.06	2	0.73
Inter-item latencies	Young	0.02	0.4	0.22	0.31
	Older	-0.09	0.33	0.25	0.46
	AD	0.36	0.61	0.37	0.4

Note. M = Mean; SD = Standard deviation. Inter-item latencies are displayed as mean Z-scores.

MANCOVA results. As stated previously, it was decided to control for the effects of vocabulary. The required criteria for the test for homogeneity of slopes were met, and therefore the MANCOVA was executed. By doing so, findings showed that after controlling for vocabulary, a significant effect was still present in phonemic VF, including the number of correct words, $F(1, 60) = 17.34, p < .001$, number of clusters, $F(1, 60) = 4.01, p = .050$, switching, $F(1, 60) = 12.87, p = .001$, and inter-item latencies, $F(1, 60) = 11.07, p = .001$. In semantic VF, significant effects remained significant after controlling for vocabulary in the number of correct words, $F(1, 54) = 13.84, p < .001$, the number of clusters, $F(1, 54) = 7.36, p = .009$, switching, $F(1, 54) = 8.56, p = .005$, and inter-item latencies, $F(1, 54) = 8.05, p = .006$. However, after controlling for vocabulary, intrusions, repetitions, and the size of clusters failed to show significant group differences in both VF tests.

Discussion

The aim of this study was to delineate differences in the deployment of clustering and switching within phonemic and semantic VF tests in early AD compared to normal ageing. More specifically, the objective was to find out whether clustering and switching differences in a time-course analysis could contribute to distinguish patients from normal controls. Also, to achieve a

more detailed picture of VF in normal ageing, comparison of healthy young and older adults found place.

Taking into account the stated hypotheses and expectations, the following sections will present and discuss findings from this study. First, findings of correct words, repetitions, intrusions, clustering, and switching in normal ageing and early AD will be addressed relative to the whole minute. Following, the aforementioned variables, with the addition of inter-item latencies, are discussed in relation to the time-course analysis (i.e. the first and last 30 seconds).

VF Performance Relative to the Whole Minute

Phonemic and semantic VF performance in young and older adults.

Correct words, repetitions, and intrusions. Regarding the first hypothesis (1a) it was expected that healthy young adults executed VF tasks at a higher level than older adults. In fact, this hypothesis was not confirmed, since no differences appeared. In a previous study, responses generated have been shown to decrease with age. This specifically occurs on semantic VF, which gradually decline after the age of 60 years (Tombaugh et al., 1999). It is not easy to understand the lack of significant results in semantic VF for the healthy groups. In spite of the non-significant findings, data in the present study show a marked trend towards the age-related differences on correct words in semantic VF, in line with what Tombaugh et al. (1999) found.

Clustering and switching. For the hypothesis (2a) concerning performance in clustering and switching in young and older adults, findings revealed that the older group produced fewer clusters and switches, but only in the semantic VF task. There was, as previously reported (Brucki & Rocha, 2004; Haugrud et al., 2010), no difference in cluster size in any VF task. Regarding the decline in the number of clusters, researchers have pointed towards processing speed and inhibitory capacity as predictors of VF performance in older adults (Mayr & Kliegl, 2000; McDowd et al., 2011). The fact that the young group of adults in the present study had

more years of education could be one of the reasons to why differences applied in the semantic task but not the phonemic. While vocabulary may mediate good performance in phonemic clustering, education could have impacted semantic clustering, leading to younger adults producing a higher number of clusters based on their higher education (Zimmerman et al., 2014).

Switching in semantic VF was also found to be less employed by older adults compared to the younger group, replicating previous findings (Brucki & Rocha, 2004; Haugrud et al., 2010; Troyer, 2000). The underlying mechanism suggested from these studies has been argued to be impaired ability of shifting attention between information retrieved from semantic memory stores.

Phonemic and semantic VF performance in normal ageing and early AD.

Correct words, repetitions, and intrusions. For the patients with early AD, it was expected that (1b) AD patients would produce fewer correct words and make more repetitions than healthy elderly in both tasks. Findings revealed that AD patients produced fewer words, and made more repetitions in both VF tasks, as expected from previous research (March & Pattison, 2006; Murphy et al., 2006; Suhr & Jones, 1998). Based on these findings, fewer words would reflect an impaired memory capacity. Furthermore, because of a limited number of available words, responses that are available are more readily repeated, although the perseverance in AD may also be due to deficits in working memory and the monitoring of already generated responses (Collette et al., 1999).

Clustering and switching. Regarding the hypothesis (2b) of clustering and switching, early AD patients were expected to produce fewer and smaller clusters compared to older adults, especially on the semantic task, because of the effect the disease has on memory organization and retrieval. AD patients were also expected to switch less frequently than healthy elderly, due to exaggerated executive dysfunction.

This study revealed that AD patients produced fewer clusters in both VF tasks, but the size of these did not differ from healthy older adults. Switching was only impaired in semantic VF. Regarding the decreased number of clusters in patients with early AD, Gomez and White (2006) also found the same results in their assessment of very mild AD patients. According to notions of how semantic clustering should be more impaired than phonemic clustering (Beatty et al., 1997), the current findings did not support this statement, which could possibly be due to a small sample size. In one study where VF was administered as usual, but also in an alternating variant requiring shifting between categories (e.g. *animal, furniture, animal, furniture*), the latter made clustering harder for controls. AD patients, on the other hand, showed similar impairment on both types of VF (McDowd et al., 2011), further supporting the notion of semantic memory impairments in early AD.

Considering the size of clusters, AD patients did not differ from controls. This finding has previously been reported (Bertola et al., 2014; Epker et al., 1999), but researchers have also shown the opposite (Beatty et al., 1997; Weakley & Schmitter-Edgecombe, 2014). One reason for this inconsistency could be that calculations of clustering often exclude errors (Haugrud et al., 2010). Moreover, the criteria for the number of words required for a set of words to be considered a cluster varies across studies. The present study included the rates of intrusions and repetitions, which should, if anything, increase the likelihood of differences in cluster size. Perhaps cluster size is not sensitive enough for identifying AD, and may not provide additional information beyond the other measures of VF (Gomez & White, 2006).

Switching, on the other hand, was found to distinguish older controls and AD patients, but only in semantic VF. Based on research that also revealed this difference (Raoux et al., 2008), the switching deficit in the context of intact clustering could point to executive problems with

shifting attention, monitoring responses, and even distinguishing from the words retrieved from memory (Troyer et al., 1998).

VF Performance Relative to the First 30 Seconds and the Last 30 Seconds

This section will account for the questions set about VF performance relative to the course of time, more specifically the first and last 30 seconds of the minute. Because inter-item latencies were only considered relative to the time periods, findings relating to these will also be discussed in the following section.

Phonemic and semantic VF performance in young and older adults.

Correct words, repetitions, intrusions, and inter-item latencies. Regarding the hypothesis (3a), the number of correct words was expected to be similar for young and older adults during the first 30 seconds. Repetitions and intrusions, on the other hand, were not expected to change as a function of time. Inter-item latencies would likely be longer in duration for older adults compared to young adults, due to a slowing of processing information, but were expected to increase during the last 30 seconds in both groups.

The detailed time-course analysis revealed that words were generated by both healthy groups in the predicted manner, that is, with higher production of words in the first 30 seconds, followed by fewer in the last 30 seconds. Also, differences appeared in the rate of errors in phonemic VF, where older adults produced more intrusions and repetitions. However, groups showed similar patterns of performance through time. This pattern of word production replicates earlier data (Fernaes & Almkvist, 1998), which supports the notion that the first 30 seconds rely more on the automatic retrieval of words, followed by a more cognitively demanding search process in the last 30 seconds.

When it comes to errors, unfortunately, there are few data from earlier studies, because usually errors are excluded when calculating the number of correct words. The present study

revealed differences in repetitions and intrusions at specific time periods only in the phonemic task. For repetitions, the first 30 seconds were crucial to discover differences between healthy groups. For intrusions, group differences appeared in both periods of time, where the largest difference appeared in the last 30 seconds. Previous data that have addressed errors in VF tasks have reported little error generation in elderly people (Gomez & White, 2006; Stockholm et al., 2013). One reason could be that researchers have not considered data relative to time, which in the present study, appears to be a crucial aspect in revealing differences in VF performance. Errors have been noted to occur to a larger degree during the phonemic VF task, compared to the semantic task (Gomez & White, 2006), supporting the reported findings from the present study. Thus, because phonemic VF is associated with executive functions, healthy elderly seem to exhibit difficulties in maintaining information, especially during the last 30 seconds of the minute. This would suggest an impact on working memory, a part of executive functions. Furthermore, because the larger effect occurs in the last 30 seconds, postulated to involve executive functions more than memory alone, information available from memory has likely reached exhaustion (Raboutet et al., 2010), which increases the chances of repeating words.

Regarding the inter-item latencies, there were no differences between groups across time periods. Because this measure reflects processing speed, older adults would be expected to have longer latencies than young adults (McDowd et al., 2011; Salthouse, 1996). Both groups spent longer time generating words during the last 30 seconds, and thus got gradually slower towards the end of the task. Now, there was a tendency for older adults to produce longer latencies in the last 30 seconds in phonemic VF, which would suggest that older adults are likely to be more impaired in the speed of processing information when the task is difficult and requires effort, as is the case for the phonemic VF task. In a time-course analysis by Mayr and Kliegl (2000), inter-item latencies were analyzed in relation to a computed function, and the findings pointed towards

that executive function served as the most sensitive component in causing age-related differences in VF performance. Considering the clear trend of longer inter-item latencies in phonemic VF in light of the findings by Mayr and Kliegl (2000), executive dysfunction and declining processing speed may be two processes operating together in causing the poorer performance in VF in healthy elderly. For semantic VF, although age has been noted to have an effect on performance through time, this association cannot be confirmed in the present study.

Clustering and switching. For the hypothesis concerning clustering and switching in normal ageing (4a), the expectation was to observe more clusters and switches during the first 30 seconds in both young and older adults, while cluster size was not expected to change through time.

Findings revealed that clusters in older adults were only significantly fewer in semantic VF, and only during the first 30 seconds, whereas switches in semantic VF were less frequent only in the latter 30 seconds. Both young and older adults produced more clusters and switches during the first 30 seconds, with a gradually decreasing rate towards the end of the minute. Thus, findings confirm the hypothesis and the notion forwarded by Fernaeus and Almkvist (1998). Cluster size did not change through time, as expected.

In phonemic VF, young adults showed a marked exhaustion in production of clustering, which parallel execution of older adults at the end of the last 30 seconds. Although this pattern was a tendency, and not significantly different between groups, it could point to that older adults have an advantage in producing the same level of phonemic clusters across time, perhaps due to a higher verbal knowledge on lexical matching (Troyer et al., 1997). In contrast, for semantic VF, older adults perform worse than younger adults probably because they do not have this advantage. Possibly, higher education can explain why younger adults outperformed healthy elderly in semantic clustering, as suggested by Zimmerman et al. (2014). These researchers found

that knowledge learned through academic training followed a steeper decline with age, and that the degree of education therefore was more influential in younger age.

Fewer clusters during the first 30 seconds in semantic VF could also be related to a decline in memory function, in which older adults retrieve fewer words from memory stores than young adults do. This notion is also in line with how both memory and executive functions are important requirements during the first 30 seconds in VF tasks (Raboutet et al., 2010). However, memory organization is thought to remain intact with age (Federmeier et al., 2002), making this a less plausible explanation. A more likely cause is that less available information is mediated by a decline in processing speed and also failure of predicting forthcoming stimuli (Federmeier et al., 2002). Slower speed of processing may especially apply since older adults produced fewer clusters from the start, but did not differ significantly from young adults in the last 30 seconds. In relation to patterns of cluster generation through time, younger and older adults exhibited a very similar cluster generation, where more clusters were generated in the first 30 seconds, compared to the last 30 seconds, as expected.

Switching frequency did also separate the older from young adults, but only significantly in semantic VF during the last 30 seconds. Switching decline in older ages does not come as a surprise. Researchers have pointed to how executive function declines with age, and that the selective search, inhibition, self-monitoring, as well as attention shifting abilities become weaker as one gets older (Coubard et al., 2011; McDowd et al., 2011). In a previous study, differences in switching were not found between groups, and time did not affect performance (Brucki & Rocha, 2004). In the present study, on the other hand, both group and time influenced switching. Although older adults switched less in the last 30 seconds, both groups produced switches in the expected pattern suggested by Fernaeus and Almkvist (1998). These results highlight the theoretical notion of a poorer shifting of attention, postulated to play a bigger role in the latter 30

seconds of VF tasks where more effort and selective search for words are required following exhaustion of readily available information in memory. As the words retrieved from memory during the first 30 seconds are high-frequency words (i.e. words that are used in everyday language and are readily available in memory), words less frequently used are harder to access, and takes more effort to retrieve from memory (Raboutet et al., 2010).

Phonemic and semantic VF performance in normal ageing and early AD.

Correct words, repetitions, intrusions, and inter-item latencies. For the AD group, patients were expected (3b) to produce fewer correct words in a more gradual pattern through the running time, especially in the semantic task. Repetitions were expected to increase during the last 30 seconds, while intrusions were not expected to change. As for the number of words, inter-item latencies were expected to follow a more gradual pattern through time.

The findings showed that word production in patients were in fact lower during the first 30 seconds, both in the phonemic and semantic VF task. The pattern of word production was, however, similar to that observed in older adults. In line with Weakley and Schmitter-Edgecombe (2014), findings suggests a pattern of word production more like one expected for normal ageing, than pathological ageing. For the semantic task, on the other hand, the AD patients exhibited a more gradual decline. A more gradual pattern may point to how the available words in semantic memory stores are less accessible from the start, leading to a lower rate of decline during the last 30 seconds, compared to older adults. This was also the case in the study by Jones and colleagues (2006), and researchers suggested that the gradual pattern was due to deficits both in the access to and structure of stored information. More specifically, Jones et al. (2006) argued that because the more automatic retrieval (during the first 30 seconds) depends more on rapid access to information, the last 30 seconds require deliberate search and effort to find words, for which the

intact structure of memory stores are needed. Thus, a more gradual decline is observed in AD patients, often more pronounced in the semantic VF task.

Also, repetitions increased in a markedly steeper manner for patients than for older adults. In AD patients, a higher rate of repetitions could point to deficits in monitoring generated words, but could also imply deficits in semantic memory stores. As such, these patients could have fewer words available in memory from the very start, leading to the higher possibility of repeating the words already generated (Weakley & Schmitter-Edgecombe, 2014). This may be a more likely reason for the high rate of repetitions than executive dysfunction per se, since intrusion rates were not significantly different than that of healthy elderly in the present study. Also, as expected, intrusions did not change in number during the minute allocated for the phonemic and semantic task.

For the inter-item latencies, reflecting processing speed, AD patients exhibited longer time between each generated word, compared to healthy elderly, but only in semantic VF. There was also a tendency for this group to operate at the same speed of processing throughout the allocated time. In normal controls, the time used between each word increased gradually towards the end. This was expected, in line with the greater involvement of executive functions and effortful selection of words during the last 30 seconds (Fernaes & Almkvist, 1998), and a slowing of processing speed (Albinet, Boucard, Bouquet, & Audiffren, 2012). In normal ageing, these two components seem to cause age-related difficulties in VF, but that resemble a pattern of normal word generation. For AD patients, however, there seems to be a distinct course of processing speed in word generation. Processing speed does not necessarily decline during time, as in normal ageing, but is impaired from the very start. Patients were only significantly impaired as compared to older adults in the semantic task, further supporting the suggestion of semantic

memory deficits, either inaccessibility of information or the disintegration of memory stores (Henry et al., 2004).

Clustering and switching. Considering the hypothesis dealing with clustering and switching, it was expected (4b) to find no change in the number and size of clusters as a function of time in AD patients compared to healthy elderly. For switching, AD patients were expected to switch in an uneven manner throughout the allocated time.

The intricate time-course analysis revealed that only the number of clusters significantly differed from older adults in the phonemic VF task, and during the last 30 seconds. However, as for healthy controls, clusters decreased in number during the last 30 seconds. The findings by Holmen & Thorbjørnsen (2013) indicated impaired VF in both tasks, but with the greatest deficits in semantic VF. In the present study, there were no differences in the number of clusters in semantic VF, which could be due to a smaller sample size utilized for evaluation of semantic VF data. However, it may also be related to the effortful and more difficult cognitive requirements in phonemic versus semantic VF, or even the involvement of deteriorations in lexical, and not exclusively semantic, memory stores (Troyer et al., 1998). Based on investigations of clustering and switching, scientists argue that poorer clustering in AD is caused by failing to retrieve information from semantic and lexical memory stores. Especially the specific subcategory items at the higher hierarchical stages (e.g. *apple*) are more difficult to access compared to general concepts (e.g. *fruit*). As such, a deterioration of hierarchical structure of memory stores may be the underlying mechanism (Beatty et al., 1997), where the higher and more specific items become altered, damaged, or simply hindered from retrieval. While, in semantic VF, several items share a similar or related meaning with a word (such as *cow* will likely automatically activate *sheep*, *pig*, and *horse*), lexical information is thought to be characterized by fewer links between words (Burke & Shafto, 2004). This may contribute to

making phonemic VF a more difficult task, and could have been one possible reason for why phonemic clustering differentiated AD patients from healthy elderly, while semantic clustering did not. The nature of the underlying memory deficits in AD has, however, been difficult to fully comprehend and reconcile.

As previously reported (Weakley & Schmitter-Edgecombe, 2014), the size of clusters did not differ between groups or through the minute. Now, Weakley and Schmitter-Edgecombe (2014) did find that AD patients produced smaller semantic clusters. This emphasizes the semantic memory deficit acknowledged to be one of the underlying mechanisms in AD. However, AD patients did not differ in phonemic cluster size, and this measure did not change through time. If cluster size indicates the integrity of memory stores, this may perhaps involve semantic memory more than lexical.

Switching did not differentiate AD patients and older adults in any VF task. However, despite the lack of significant differences, the AD group did show a tendency of a more gradual decrease in phonemic switching frequency. This could suggest the similar trend as for the number of words and inter-item latencies reported from the present study. Impaired switching may be mediated by a lower word generation from the very start, and therefore switching does not decrease in the same way as for older adults. In terms of time, both older adults and AD patients produced clusters and switches in a gradually decreasing manner. This was also the case in the study by Weakley and Schmitter-Edgecombe (2014). In their study, healthy controls produced more switches than patients in both VF tasks. Researchers suggested the underlying mechanism for this to be executive dysfunction, which is plausible due to how the deliberate shift of attention rely on executive processes that seem to be impaired to an exaggerated degree compared to normal ageing (Coubard et al., 2011).

Thus, in normal ageing, it seems poorer VF may be down to an age-related decline in executive functions and processing speed, while early AD brings the abnormal development of memory organization and/or retrieval. The semantic component has been shown to play a great role for AD patients in VF, as patients show a distinct pattern of processing speed and word generation in semantic VF. However, lexical memory could also be an important component in the development of AD, due to the finding of impaired clustering in phonemic VF. Although phonemic VF is associated with executive function more than memory capacity, the poorer clustering in early AD in this VF task is likely not due to executive dysfunction alone, but may instead operate in combination with abnormal memory impairments. The plausibility stands even stronger after VF performance was controlled for vocabulary, of which intrusions and repetitions, indicative of executive functions, lost their predictive value. Thus, apart from deterioration of semantic and/or lexical memory stores, the efficient and rapid access to these is likely also impaired in early AD.

The effect of vocabulary. Also important to note is the impact of vocabulary. This became apparent after controlling for this variable in the present study. After doing so, significant differences found in intrusions, repetitions, and cluster size were no longer present. This highlights the importance of vocabulary influence on VF performance, and should be considered in future research.

Limitations

In the present study, the only significant qualitative VF measure that differed significantly between older adults and early AD patients was clustering in the phonemic VF task. This could be explained in terms of the difficulty of the task, and also relative to the mild stage of AD. On one side, the phonemic VF task is more demanding, and on the other side, the patients are still capable to perform semantic clustering to some degree. This finding was unexpected, and needs

to be further investigated by replications using larger samples. In comparison to the larger sample size used in the study by Weakley and Schmitter-Edgecombe (2014), the present study only included 19 AD patients and 22 controls, of which data evaluated from the semantic VF task comprised only 13 of the patients. Probably, with a larger sample of older adults and AD patients, it would be possible to find significant differences beyond that discovered in phonemic clustering. Another important aspect to keep in mind is that Weakley and Schmitter-Edgecombe (2014) tested patients with mild-to-moderate AD, while in the current study patients were at the very early phases of the disease.

Another issue concerns the scoring procedures. Semantic clustering and phonemic clustering should not be considered exclusive to one specific VF task, which has often been the case. People may sort words into clusters based on lexical properties and meaning in both phonemic and semantic VF. For example, when given the stimulus *S*, the successively generated words *sweet*, *sour*, and *salty* relate by meaning, and not lexical properties as scoring generally is based on. This way of sorting words became apparent in the present study, where a number of responses to a phonemic stimulus were clearly organized (by the participant) in relation to the *meaning* of the word, and not *structure*. This could have had to do with counter-balancing, as the stimuli were always given in the same order. However, the phonemic stimuli were given before the semantic, and so a bias towards semantic clustering in phonemic VF would likely not be the case in this study. By considering a less restrictive scoring approach, it would probably increase the cluster scores, and possibly reveal larger differences.

Also, the type of semantic category may cause marked differences in clustering, such as the category *fruits and vegetables*. People think of and organize fruits and vegetables in a range of different ways, relative to influential factors of culture and economy, for example. Therefore, in the present study, clusters of fruits and vegetables tended to be large and more general. This

may also have attributed to semantic clustering being a less sensitive measure, although this only regarded one of the categories (i.e. *fruits and vegetables*). Therefore, deciding the type of stimulus and refining rules for scoring based on category should be considered closely before assessment. This could provide better means for avoiding inconsistencies of results, and improve VF as a tool for identifying word production impairments in ageing populations.

Summary of Results

Concerning the healthy elderly, the present study revealed that older adults exhibit difficulties with sustaining and monitoring information during the first 30 seconds of the phonemic VF task, indicated by the higher rates of repetitions and intrusions, compared to younger adults. The higher number of intrusions at the end of the phonemic task may further point to the difficulty of remembering the rules of the task (such as avoiding proper nouns and very similar words). This would suggest a poorer short term memory function. Moreover, clustering and switching was also different from younger individuals. In the semantic task, older adults generated fewer clusters in the first 30 seconds and fewer switches in the last 30 seconds. These findings indicate that older adults keep to the same strategy for a longer time, but that they are unable to find new clusters, due to getting tired at the end of the trial. In sum, healthy elderly seem to use verbal knowledge differently through the allocated time, present reduced working memory capacity, and less efficient executive ability.

For the AD patients, on the other hand, there seems to be changes distinct from normal ageing. Patients exhibited lower performances than older adults in the semantic VF task, and at the beginning of the task (i.e. the first 30 seconds). Unexpectedly, differences in phonemic VF were also significant: Patients produced fewer clusters than did older adults, specifically at the end of execution (i.e. the last 30 seconds). Impairments in semantic VF supports the often reported word-finding difficulty in AD, as observed by fewer correct responses, to produce words

less efficiently and rapidly, indicated by a slower processing speed, as well as the higher perseveration in patients, reflected by the higher rates of repetitions at the end of the trial. Thus, the present study indicates that patients with early AD suffer from semantic memory deteriorations and slowing of processing speed from the very beginning of the VF task, as well as executive dysfunction, because they struggle with monitoring words in working memory during word production. Regarding the significant difference during the last 30 seconds on cluster generation in the phonemic VF task, there remains uncertainty whether this is a reliable indicator of executive dysfunction, or if this finding could be due to fatigue on a cognitively demanding task like phonemic VF.

Conclusion

In conclusion, it has been demonstrated that a time-course analysis approach including all measurements of VF performance is valuable to identify changes through time in normal ageing and early AD. By doing so, VF as a sensitive measurement distinguishing AD patients from healthy elderly was supported. This also includes the strategies of clustering and switching, which may serve as valuable indicators of early AD.

Future investigations should conduct a VF analysis of AD patients' performance during the first 30 seconds, especially in the semantic VF task, and compare these to other dementia states to understand whether the present results are unique to AD or not.

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