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Increasing stimulus duration improves attention and memory performance in elderly with cognitive impairment

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Abstract

Objectives: In this study, we investigated whether increasing stimulus duration could improve performance on a test of attention and short-term memory in cognitively impaired individuals.

Methods: A computer-generated forward digit span test was administered to 65 patients with mild cognitive impairment or dementia (28 intervention and 37 controls). After point of failure, testing in the intervention group was continued at the same rate, but with an average 150% digit lengthening to 800 ms. Testing of controls was continued using the standard digit span test.

Results: In the intervention group, 13/28 (46.4%) improved their digit span test performance, compared to 2/37 (5.4%) in the control group ($p = 0.00005$).

Conclusion: Cognitively impaired elderly participants improved performance on a test of attention and short-term memory, when stimulus duration was increased in proportion to elongation of the finger tap touch-phase previously found in a similar cohort. A possible mechanism for the effect of increased stimulus duration on attention and short-term memory is discussed.

Keywords

Geriatrics/gerontology, mental health/psychiatry, dementia, digit span, Alzheimer's disease, working memory, attention, finger tapping, stimulus duration

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Introduction

Dementia is characterized by deficits in multiple cognitive domains, two of which are attention and short-term memory (STM). Both attention and STM are considered to be components of working memory (WM).[1,2]

The widely used model of WM proposed by Baddeley[2,3] includes the central executive, a control system of limited attentional capacity and two storage systems: the phonological loop which is based on sound and language and the visuospatial sketchpad. The attentional component regulates and processes the delivery of items into and out of the two storage systems, as well as retrieves information from other memory systems such as long-term memory.

It is well known that deficits in attention and STM have a profound effect on activities of daily living as well as on interpersonal communication.[3,4] Effective communication with persons with dementia is crucial and one common recommendation is to speak slowly.[5]

However, empiric evidence does not support this recommendation. A study of communication between caregivers and persons with Alzheimer's dementia (AD), which used a self-report questionnaire and audio-recorded interactions did not find slow speech to be effective.[6]

Several studies have demonstrated that slower speech rate has, in fact, a detrimental effect on communication.[7] In a study of 15 patients with mild-to-moderate Alzheimer's disease,[8] comprehension did not improve for sentences presented at a

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slower speech rate. In another study which included three Alzheimer's subjects, slow speech rate was beneficial only for the subject with the most preserved WM. Slow speech rate did not affect comprehension for the subject with moderately impaired WM and was actually detrimental for the subject with the most severe WM impairment.[9]

The lack of efficacy of speaking slowly was explained by WM loss, with resultant inability to maintain time-stretched (longer) verbal information in the short-term storage.[8]

However, slowing of speech rate involves an increase in both word duration and silence (inter-stimulus) duration. While, as mentioned above, slowing of speech does not improve memory, relatively little is known of the effect of an increase in word (stimulus) duration only, while keeping total speech rate unchanged.

A study in healthy young subjects has demonstrated that increasing word duration on a visual word list test decreased false recall.[10] In a study of 122 normal undergraduates, increased resistance to forgetting at longer retention intervals was found for auditory digit sequences at longer digit durations and inter-digit intervals.[11] A few studies have investigated the effect of increasing stimulus duration on perception (awareness of a sensory stimulus), in healthy individuals.[12–14] These studies have employed awareness scales and task accuracy measurements and have demonstrated that both improve as a function of stimulus duration. Using a simple masked visual identification task, Sandberg et al.[12] demonstrated that this relationship can be depicted as a sigmoid function. An earlier study demonstrated the relationship as a linear one.[13] In both studies, the increase in perception was most pronounced along a continuum of stimulus durations from 50 to ca 150 ms. These results are compatible with an earlier study that demonstrated that conscious perception of words was significantly higher for those presented for 500 ms than for those presented for 50 ms.[14]

A possible explanation for the positive effect of increased stimulus duration on STM is that increasing stimulus duration allows more time for attentional control.[10]

More evidence for a relationship between stimulus duration and attention can be found in studies of finger tapping tasks.

An example for such a task is self-paced finger tapping (SFT), in which the participant is required to reproduce equal temporal intervals, by tapping a finger as regularly as possible at a self-chosen rate. The relevant stimulus to be attended to in this task is the touch phase of the finger tap (the time between onset and offset of the finger tap): the brain must allocate attention to the event of the finger contacting the pad in order to assess the temporal interval elapsed from the previous touch phase and reproduce it as accurately as possible in the next finger tap.

Empirical support exists for an involvement of an attentional mechanism in the finger-touch phase.[15–18]

For example, the importance of the discreteness of this phase was shown in a study[15] that demonstrated lower timing variability when finger tapping was compared to continuous movement (finger remains on sensor). The discreetness of the tap event was thought to increase the central nervous system's (CNS) certainty in timing of movement onsets. An analysis of the different phases of spontaneous finger tapping in college students with attention deficit hyperactivity disorder (ADHD) demonstrated increased variability of the touch phase, but not the off-phase (the time between offset and onset of the finger tap), compared to controls.[16] A detailed analysis of the tap phases in the Halstead–Reitan Finger Tapping Test (tapping as rapidly as possible) has recently demonstrated that the stationary phases of the finger tap (which are essentially similar to the touch phase), but not the movement phases, became slower and more variable under concomitant attentional tasks.[17]

In a previous study, we used a detailed analysis of the two main phases of SFT, the touch phase and the off-phase, in order to investigate their relationship to cognitive function.[18]

The main result was an average increase in 150% in the length of the touch phase in elderly participants with cognitive impairment (mild cognitive impairment (MCI) or dementia) compared to normal controls (298 versus 203 ms, respectively; $p=0.001$).[18] This increase was significantly related with poor performance on tests of attention and STM. An association between the touch phase and attention was specifically demonstrated by the approximately 150% lengthening of this phase in participants with poor performance on the forward digit span test (DST; Figure 1), a test of attention and STM.[19]

It is noteworthy that in these participants, no significant lengthening occurred in the t-off period (from lift off to next contact), further supporting the notion that the mechanism involved is not purely motor. As peripheral sensory nerve conduction speed does not differ significantly between patients with Alzheimer's disease and controls,[20,21] the elongation of the touch phase must be explained by a CNS mechanism.

Based on the evidence that an attentional mechanism is involved in the finger-touch stimulus, we propose that the significantly longer touch phase observed in cognitively impaired individuals reflects an attentional requirement for longer stimulus duration.

These may indicate that cognitively impaired people require longer stimuli in tasks that involve attention. This phenomenon may be more general and could be observed also in other modalities and tasks.

It has been demonstrated that in patients with Alzheimer's disease, attention was the most impaired component of WM.[22] An attentional deficit may lead to incomplete loading of items into the storage systems and consequently to incomplete retrieval on attention and STM tasks, for example, failure on the DST.

Can increased stimulus duration improve memory performance by compensating for the above attentional deficit?

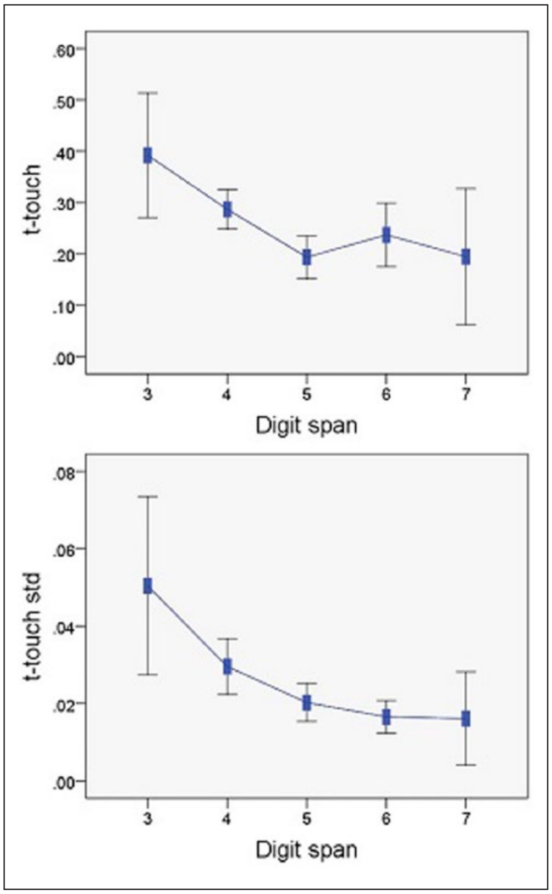

Figure 1. T-touch average duration (top) and standard deviation (bottom) versus digit span. Length of t-touch was inversely and significantly related to performance on the digit span test (Spearman's $\rho = 0.30$, $p < 0.001$). No significant association between t-off and digit span score was observed (Spearman's $\rho = 0.10$, $p = 0.21$; data derived from article I).[18]

In this study, we tested the hypothesis that increasing stimulus duration could enhance attention and STM performance in people with dementia or MCI. For this purpose, we used the forward DST, a test of attention and STM, in which digit duration was increased in proportion to the 150% t-touch elongation found in our first study.[18]

Two groups of people with dementia or MCI participated in the study. The first (control) group received the regular DST, whereas the second (intervention) group received a modified test with increased duration of digits. If our hypothesis is correct, we expect that a significant number of people in the intervention group would improve performance on the DST compared to the control group.

Methods

Setting

The setting was a community-based geriatric assessment unit that serves the greater Haifa and Western Galilee districts. The unit performs a comprehensive geriatric assessment of elderly patients who are referred from primary care clinics and includes screening tests for various geriatric syndromes including cognitive decline and a full cognitive examination when dementia is suspected.

Participants

The participants included 165 consecutive patients, all with a diagnosis of MCI or dementia (83 in the control group and 82 in the intervention group) who underwent geriatric assessment during a 4.5-month period in 2011 (a non-randomized allocation procedure was applied according to period of geriatric assessment; control: 3 April–6 June; intervention: 2 October–18 December).

Exclusion criteria included a history of cerebrovascular disease or parkinsonism due to accompanying motor impairment (control: 25/intervention: 27), lack of education to the degree of unreliability of cognitive test scores (4/2), severe anxiety or depression to a degree affecting attention to instructions (6/7), no knowledge of test language (Hebrew) with inability to comprehend digits (3/3), severe dementia to a degree of inability to comprehend finger tapping instructions (1/4), significant hearing impairment (3/4) and several other miscellaneous causes (wrist fracture, elbow contusion, drowsiness due to sleep apnea, mental retardation, symptomatic meningioma, recent brain surgery, severe pain and febrile illness) (4/7). See Figure 4 for patient recruitment flow chart.

The remaining 65 participants (81.4 ± 5.4 years) underwent finger tapping analysis and digit span testing at the end of their geriatric assessment. These included 37 participants in the control group (81.4 ± 5.7 years) and 28 participants in the intervention group (81.5 ± 5.0 years). There was no significant difference between the two groups in both age ($t_{63} = 0.043$, $p = 0.97$) and gender ($\chi^2(1) = 0.03$, $p = 0.86$).

Clinical assessment

The clinical assessment included screening tests for cognitive decline and a full cognitive examination (carried out by one of the authors, I.R.) when dementia was suspected.

Cognitive screening tests included the Mini-Mental State Examination (MMSE) and three-word recall (extracted from the MMSE) and were administered to all participants. The MMSE is a 30-item interviewer-administered assessment (score range: 0–30) of several dimensions of cognitive function. Its internal consistency reliability is acceptable with Cronbach's αs in the range of 0.54–0.96; test–retest reliability is moderate to high with correlations of 0.38–0.99 at intervals <2 months. The MMSE has good concurrent validity with correlations of 0.70–0.90 with other measures of cognitive impairment.[23] Inter-observer reliability was reported as intraclass correlation coefficient (ICC) = 0.69.[24] A score of 23 is the generally accepted cutoff indicating the

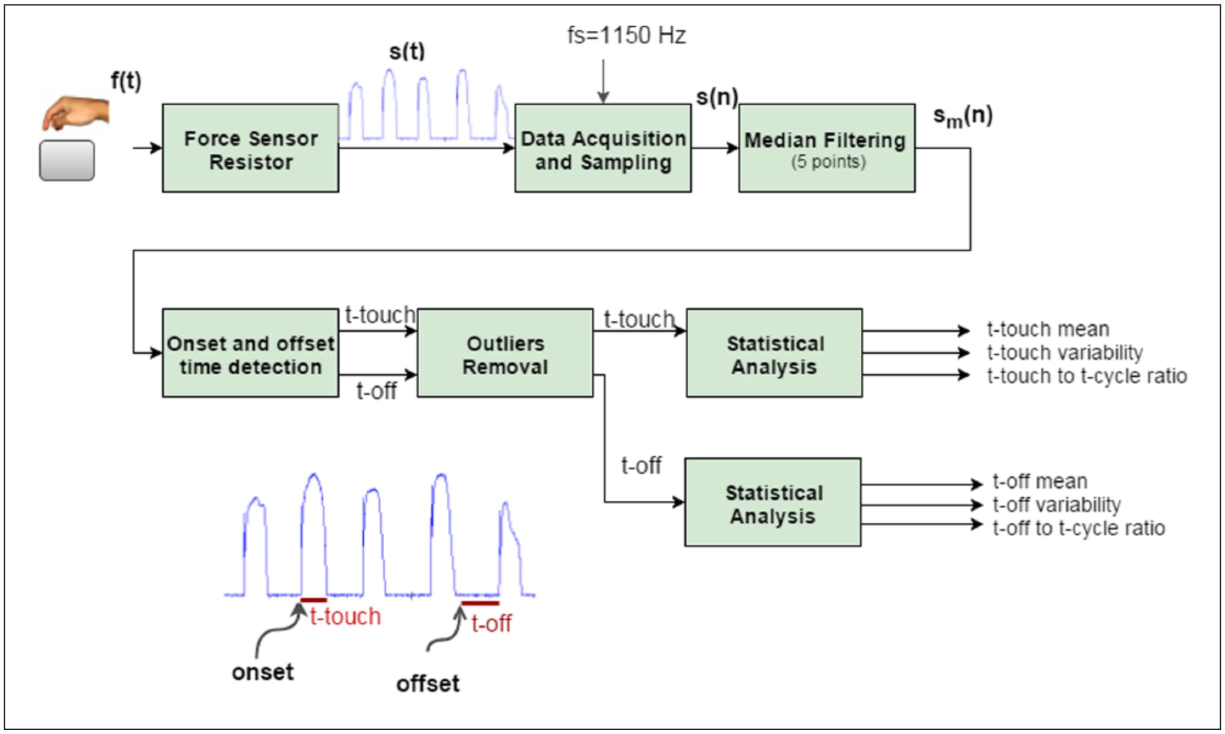

Figure 2. A schematic description of the finger tapping recording system and a block diagram of the analysis for computing finger tapping parameters.

presence of cognitive impairment[25] in the general population while a higher cutoff may be adequate for elderly with a college education.[26] Although the three-word recall test is part of the MMSE, in our view it merited a separate analysis, since a recall of less than two out of three words is associated with a 3.1 likelihood ratio for dementia.[19] Conversely, recall of two or three words is associated with a significantly reduced likelihood ratio.[27]

MCI was defined according to the Petersen criteria as memory impairment without other cognitive disorders and preserved function in daily life.[19,28,29] Definition of dementia was in accordance with the *Diagnostic and Statistical Manual of Mental Disorders*.[30] These entities were considered as one group in our study because both are pathological and considered to be on the same cognitive continuum, MCI having an approximately 12% yearly conversion rate to dementia.[29]

The diagnosis and medical recommendations were given at the end of the evaluation after completion of all tasks, including the finger tapping task; therefore, tapping was not influenced by knowledge of diagnosis.

Finger tapping. At the end of the assessment, each participant was asked to tap for 15 s on a pressure pad, using the index finger of his or her dominant hand. The participants were asked to tap as regularly as possible, at a comfortable rate. Finger tapping was recorded using a touchpad mounted on a pressure transducer (force sensing resistor (FSR); InterLink Electronics, Camarillo, CA, USA) connected to a data acquisition card (DAQ 1208LS; Measurements Computing, Norton, MA, USA). The pressure signal was sampled and digitized using a sampling rate of 1150 Hz and recorded on a personal computer, with an interactive computer program, for later analysis. The activation of the pressure sensor and the recording was carried out with MATLAB Data Acquisition Toolbox, Version 2.15. The recording and analysis systems are depicted in a schematic block diagram (Figure 2).

The finger tapping signal was pre-processed using the following procedures: (1) a five-point median filtering was applied to remove impulse or spiky noise, (2) detection of onset and offset points of each finger tap was carried out, using two pre-determined threshold values which were found empirically and (3) detection and elimination of outliers, such as long periods of delay between taps, especially at the start and end of the recording was applied. Then two time series were obtained: one containing the t-touch durations and the other the t-off durations.

The following parameters were measured to assess the relationship between finger tapping and cognitive function: (1) t-touch, defined as the time between onset and offset of the finger tap (Figure 2), (2) t-off, defined as the period between offset and onset of the finger tap and (3) t-cycle, defined as the period between onset and next onset. The mean and the standard deviation of the t-touch and t-off time series were computed, as well as the coefficient of variation and the t-touch-to-t-cycle ratio. More details on the finger

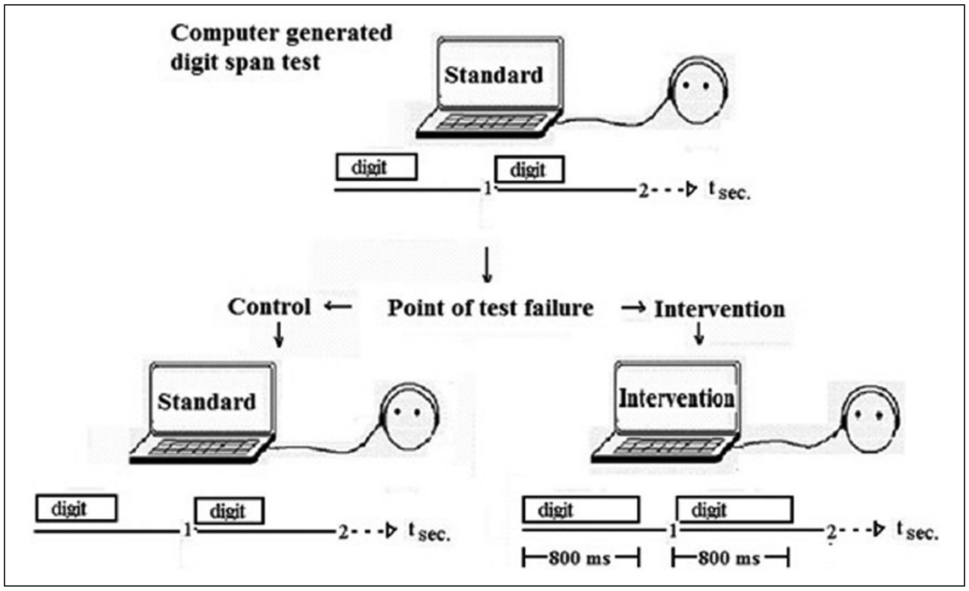

Figure 3. Study design. A computer-generated forward digit span test (DST) was administered to each patient at the standard 1-digit/s rate. Test failure was defined as the number of digits in which the patient failed to repeat all the digits in the correct sequence after two attempts. After point of failure, testing in the intervention group was continued at the same rate of 1 digit/s, but with an average 150% increase in digit duration to 800 ms. In the control group, testing was continued using the standard DST. The patients in the control group were tested using the standard DST, until a second point of failure.

tapping signal processing and statistical analysis can be found in Rabinowitz and Lavner.[18]

DST. In the forward DST, the participant is required to repeat series of growing length of random digits presented at a rate of one digit per second.[31] The DST is a subtest of the Wechsler Memory Scale (WMS) of the Wechsler Adult Intelligence Scale (WAIS), with a reliability coefficient of 0.80–0.89[32] and validity for WM as expressed by confirmatory factor analysis with factor loadings in the range of 0.73–0.77.[33] Normative values for the forward digit span in the general elderly population have been shown to be in the range of 5.[34]

A computer-generated forward DST, a test of attention and STM,[19] was administered in Hebrew to each participant at the end of the evaluation. In this test, the participant was requested to repeat in correct order several digits presented to him or her. A recall of less than five digits is associated with a 7.1 likelihood ratio for dementia.[19] Conversely, a recall of six or seven digits is associated with a significantly reduced likelihood ratio.[27]

The digits for each test sequence were randomly chosen using a random number generator, with each digit appearing only once in a sequence. The length of each sequence could be selected by the administrator. The digits were recorded in advance using a male speaker, sampled and digitized at 44,100 Hz and were played through earphones at a rate of one digit per second, the standard rate of administration of the DST.[19] Two attempts were offered for each sequence, beginning with a four-digit test.[31] Correct repetition of all digits in the correct order qualified as success and led to a five-digit test and so on up to seven digits. Test failure was defined as the number of digits at which the patient failed to repeat all of the digits in a sequence in the correct order, and span was considered to be the previous sequence length. For example, for a patient who succeeded in repeating five out of five digits in the correct order, but failed to do so when presented with six digits, the point of failure was six, and the digit span was 5.

This slight modification of the more commonly used method of two different sequences under each digit length was employed to compensate for the purely auditory nature of digit span administration in this study (in contrast to verbal administration by an assessor, where both hearing the voice and reading the lips are possible). Modifications of the digit span have been employed before in cognitive research and included changing number of repetitions per sequence and use of revised scoring methods.[35–37]

The participants in the intervention group ($n=28$, mean age: 81.5 ± 5.0 years, male/female: 10/18) were tested from point of test failure at the same recommended 1-s interval, but in this test, each digit utterance was elongated to 800-ms duration, that is, the digits were time-stretched by a factor which is the ratio between the mean t-touch of people with impaired cognitive diagnosis to that of people without impairment. The logic behind this stretching is explained in the "Introduction" section. This test was continued until a second point of failure occurred. In the control group ($n=37$, mean age: 81.4 ± 5.7 years, male/female: 14/23), testing was continued using the standard DST (i.e. without modification of digit utterances), until a second point of failure. This was done in order to ensure that, should improvement occur, it would not be solely due to test repetition (Figure 3).

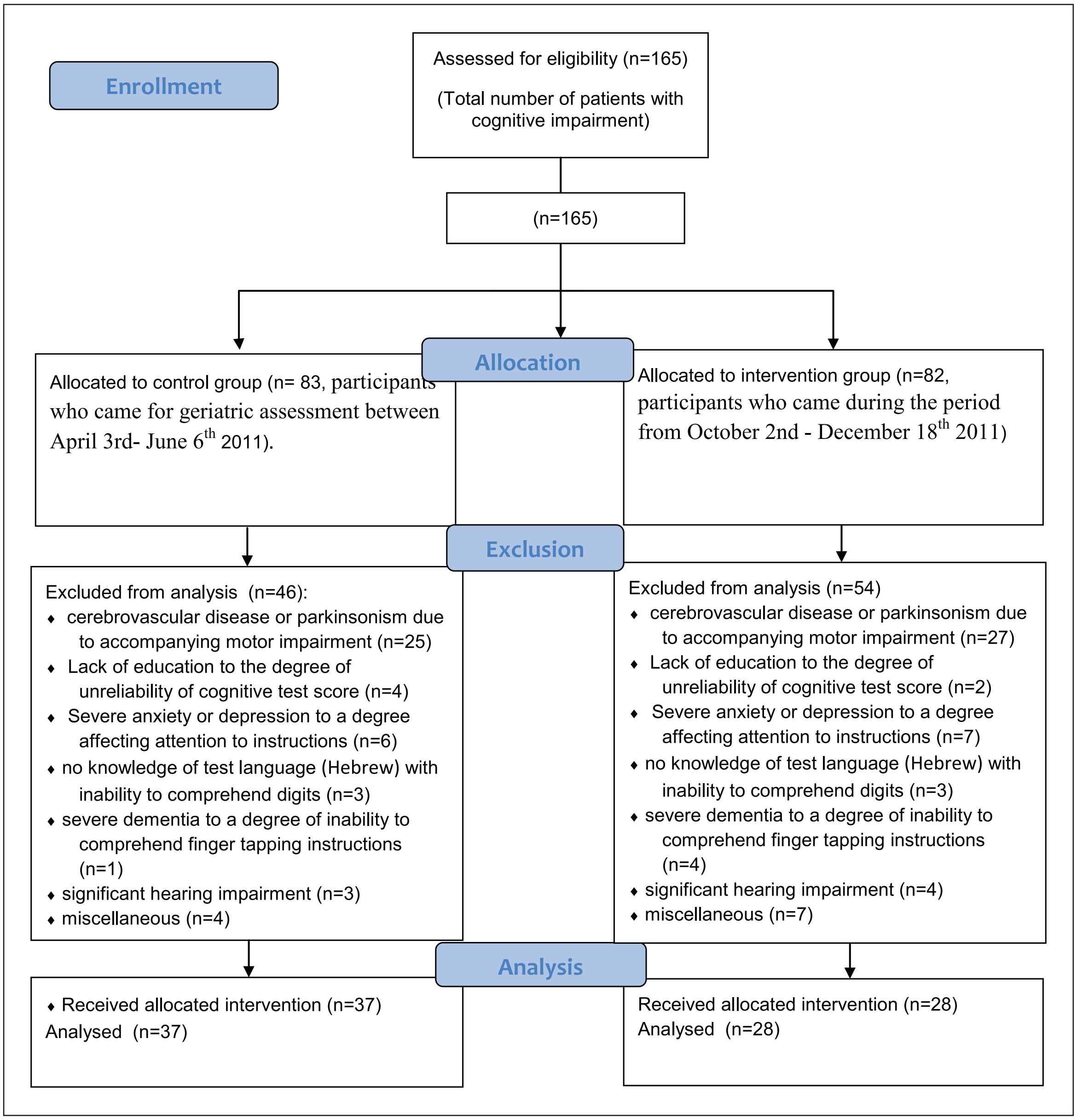

Figure 4. Patient recruitment flow chart.

The rate of 1 digit/s remained constant since this is the standard rate of administration of the DST, and for which the test was validated.[19]

A natural voice quality was maintained using the Waveform Similarity Overlap and Add (WSOLA) algorithm for time-scale modification (TSM) of speech.[38] TSM of speech is the process of modifying the duration of a speech signal, while maintaining other qualities, such as the pitch and the timbre, unchanged.[39] As such, the intonation of the digits was kept intact. Moreover, because the digit utterances were recorded separately (i.e. not as a sequence) in advance, the known problem of affecting the digit span with pitch dropping at the final digit was avoided.[40]

Analysis of the digit span results was performed only after completion of data collection, and the data were analyzed anonymously. Therefore, the intervention had no effect on diagnosis and treatment recommendations.

Ethics

Ethics approval was obtained from the Meir Hospital Institutional Review Board, which oversees community research in our district. The study purpose was explained simply: to investigate the relationship between tempo and memory. The intervention had no effect on diagnosis and treatment and virtually no demand on the participants' time (approximately 2 min for tapping and the DST).

Table 1. Comparison of demographic, cognitive and t-touch parameters between cognitively impaired patients (diagnosis of mild cognitive impairment or dementia) in the intervention and control groups and the number of patients with improvement on digit span test.

	Intervention group	Control group	Significance
Number of cognitively impaired patients	28	37	
Age (years)	81.5 ± 5.0	81.4 ± 5.7	$t_{63}=0.043$, $p=0.97^{(1)}$
Males/females	10/18 (35.7%)	14/23 (37.8%)	χ^2 (1) = 0.03, $p=0.86^{(2)}$
MMSE (mean)	21.9 ± 4.3	21.6 ± 4.5	$U=483$, $p=0.647^{(3)}$
0 or 1 out of 3-word recall (no. of patients)	14 (50.0%)	23 (62.2%)	χ^2 (1) = 0.96, $p=0.33^{(2)}$
2 or 3 out of 3-word recall (no. of patients)	14 (50.0%)	14 (37.8%)	
Digit span test—mean (med)	4.2 ± 0.6 (4)	4.1 ± 0.5 (4)	$U=478$, $p=0.50^{(3)}$
Mild cognitive impairment (no. of patients)	10 (35.7%)	9 (24.3%)	χ^2 (1) = 1.00, $p=0.32^{(2)}$
Dementia (no. of patients)	18 (64.3%)	28 (75.6%)	
T-touch length (seconds—mean)	265 ± 129	290 ± 162	$t_{63}=0.67$, $p=0.51^{(1)}$
T-touch variability (coefficient of variation)	0.34 ± 0.09	0.40 ± 0.21	$t_{63}=1.53$, $p=0.13^{(1)}$
T-touch/t-cycle ratio	0.38 ± 0.12	0.37 ± 0.11	$t_{63}=0.19$, $p=0.85^{(1)}$
Improvement in digit span test (no. of patients)	13 (46.4%)	2 (5.4%)	χ^2 (1) = 15.11, $p=0.00005^{(3)}$

MMSE: Mini-Mental State Examination.
$^{(1)}$t-test.
$^{(2)}$Pearson Chi-square test.
$^{(3)}$Mann-Whitney U test.

Therefore, the committee approved a verbal consent procedure.

Statistical analysis

Statistical analysis was performed using SPSS 19.0 (SPSS, Chicago, IL, USA). Comparisons of continuous variables between participants in the intervention and control groups were performed either by the *t*-test or by the Mann–Whitney (MW) test when appropriate. Pearson's χ^2 test was used for comparisons of categorical variables between the intervention and control groups. All *p*-values were two-sided, except in DST scores, where improvement in the intervention group was expected and statistical significance was defined as $p<0.05$.

Results

A total of 65 elderly participants (81.4 ± 5.4 years, males/females: 24/41) were included in the analysis after exclusion (see the "Methods" section), all with cognitive impairment (MCI or dementia).

The results of the cognitive examination and the finger tapping test are summarized in Table 1. It can be seen that the intervention and control groups were similar in MMSE score (21.9 ± 4.3 in the control group and 21.6 ± 4.5 in the intervention group; MW test, $U=483$, $p=0.647$), three-word recall (14 out of 28 recalled 2–3 words versus 14 out of 37, respectively, $\chi^2(1)=0.96$, $p=0.33$) and digit span scores (4.2 ± 0.6 versus 4.1 ± 0.5, respectively, $U=478$, $p=0.50$). In addition, there were no significant differences in diagnoses of MCI and dementia (10 diagnosed with MCI and 18 with dementia in the control group versus 9 with MCI and 28 with dementia in the intervention group, $\chi^2(1)=1.00$, $p=0.32$).

There was no significant difference between the two groups also in the finger tapping parameters (Table 1). The mean t-touch length (265 ± 129 versus 290 ± 162 ms, $t_{63}=0.66$, $p=0.51$), variability, as measured using the coefficient of variation (0.34 ± 0.09 versus 0.40 ± 0.21, $t_{63}=1.53$, $p=0.13$), and the mean t-touch to t-cycle ratio (0.38 ± 0.12 versus 0.37 ± 0.11, $t_{63}=0.19$, $p=0.85$) were all similar.

The measures of finger tapping reported here are similar to those found in our previous study,[18] where a comparable group of MCI and dementia was also used: the mean t-touch in this study ($n=65$) was 280 ± 148 ms, compared to 298 ± 193 ms in the former study ($n=104$), $t_{167}=0.67$, $p=0.51$, t-touch variation (0.37 ± 0.17 compared to 0.41 ± 0.19, $t_{167}=1.11$, $p=0.27$) and t-touch to t-cycle ratio (0.37 ± 0.11 compared to 0.38 ± 0.13, $t_{167}=0.43$, $p=0.67$). However, the mean t-touch found here is significantly higher than the corresponding parameter of the cognitively intact group (203 ± 129 ms, $n=66$, $t_{129}=3.15$, $p=0.002$) reported in the previous study, as expected (see Rabinowitz and Lavner[18] and the "Introduction" section).

To examine the hypothesis that cognitively impaired people require longer stimuli in tasks that involve attention, we modified the duration of digits presented to people in the intervention group while keeping the presentation rate unchanged.

Thus, in the intervention group, after the point of failure, the digits were administered at the same rate of 1 s per digit, but each digit utterance was time-stretched to a duration of 800 ms. For the control group, the test after point of failure was at a regular rate of one digit per second, with the original duration of the digits.

In the intervention group, 13 out of 28 participants (46.4%) improved their performance on the DST, compared to 2 out of 37 participants (5.4%) in the control group. Therefore, there was a significant association between the duration extension of the digits and the improvements of the participants in the DST (Pearson χ^2 test, $\chi^2(1) = 15.11$, $p = 0.00005$; Table 1). This may represent the fact that, based on the odds ratio, the odds of participants improving in the DST were 15.2 times higher if they were in the intervention group (and therefore exposed to longer stimuli duration) than if they were in the control group.

Within the intervention group, we compared the finger tapping parameters between the group of all the patients who improved after point of failure (group 1), and those who did not improve (group 2). No significant differences have been found between the two groups in all the finger tapping parameters, including the mean t-touch (235.8 ± 122.1 versus 291.1 ± 132.9 ms, for groups 1 and 2, respectively, $t_{26} = -1.14$, $p = 0.265$), t-touch variation (0.34 ± 0.10 versus 0.33 ± 0.09, $t_{26} = 0.42$, $p = 0.953$) and t-touch to t-cycle ratio (0.36 ± 0.13 versus 0.39 ± 0.11, $t_{26} = 0.69$, $p = 0.496$).

Discussion

In a previous study of 170 elderly participants, we found a significant average increase in 150% in the length of the mean touch phase (t-touch) of SFT in participants with cognitive impairment compared to normal controls (298 versus 203 ms, respectively, $p = 0.001$). This increase in t-touch correlated specifically with poorer attention and STM (18; Figure 1). The touch phase is an important stimulus for the production of even tapping[15] and has been shown to involve an attentional mechanism.[16–18] Therefore, the elongation of this phase in cognitively impaired individuals, confronted with the task of producing an even tapping rate, may reflect an attentional requirement for longer stimulus duration.

Based on this, we hypothesized that increasing stimulus duration in proportion to the t-touch elongation observed would lead to better performance on a test of attention and STM in cognitively impaired individuals.

The results confirmed our hypothesis. In a cohort of cognitively impaired elderly participants, significantly more participants improved their performance on the DST, when digit utterances were time-stretched in proportion to t-touch elongation previously found in our first study (13/28 participants (46.4%) in the intervention group, compared to 2/37 participants (5.4%) in the control group (Pearson's χ^2 test, $p = 5e-5$, odds ratio = 15.2)).

To the best of our knowledge, this is the first study to demonstrate an improvement in attention and STM in cognitively impaired individuals through manipulation of stimulus duration.

Our explanation for our results is therefore partly based on previous evidence that longer stimulus duration is associated with increased perception.[12–14] Because of the lack of studies similar to ours, we take the liberty to expand this explanation and offer a hypothesis based on two perspectives: cognitive and neurological.

From a cognitive-psychology perspective, the ability to retain auditory items (in this case, digits) in STM relies on adequate function of central-executive attentional control component. Adequate function of this component allows passage of the items unto a phonological store which can hold memory traces for a few seconds by means of an articulatory rehearsal process.[2]

An examination of the WM components in patients with Alzheimer's disease demonstrated that while a subgroup had phonological deficiency, the attentional deficit was more general.[22] An attentional deficit leading to a requirement for longer stimulus duration may lead therefore to incomplete loading of regular duration items into the phonological loop and consequently to incomplete retrieval (failure on the DST).

From a neurophysiological perspective, perception of a stimulus depends on a series of cortical events, which are reflected as event-related potentials (ERPs), beginning around 200 ms and continuing up to about 500 ms after stimulus onset.[41–43] This period, which is crucial for achieving stimulus perception,[41,42] is a vulnerable one. Perception of a skin stimulus, for example, can be altered by a cortical stimulus over the relevant somatosensory cortex, administered up to 500 ms after administration of the skin stimulus.[42] Another phenomenon occurring in this period, and which perhaps reflects a protective mechanism, is the attentional blink, a failure to perceive the second of two closely presented stimuli. This phenomenon, previously termed the psychological refractory period,[44] is most pronounced in the 200- to 600-ms range after onset of the first stimulus.[45,46] The attentional blink highlights the discontinuous and vulnerable nature of attention and has been shown to increase with age.[47,48]

Is this period of cortical activity more vulnerable in individuals with cognitive decline? Some evidence may be found in the comprehensively studied the P300 ERP, which is considered to reflect an early attention process required for stimulus perception,[48.49] and has been shown to be both delayed (increased latency) and weaker (decreased amplitude) in patients with dementia.[50–52] One study also specifically demonstrated a significant negative correlation between prolonged P300 in patients with dementia and digit span score.[53] Could an increase in stimulus duration compensate for these changes? While no such studies have been attempted in dementia, evidence does exist that in healthy individuals increasing stimulus duration decreases p300 latency and increases p300 amplitude.[54,55]

Our hypothesis for the observed improvement is therefore based on a framework of the multi-component WM model.[2]

We propose that cognitively impaired elderly individuals require longer stimulus duration in order to achieve the adequate cortical activation of the attentional component responsible for loading stimuli onto the neural correlate of the phonological loop. By accommodating this need and increasing stimulus (digit) duration, more digits achieved sufficient cortical activation for adequate attentional handling and subsequent incorporation into STM.

Limitations

Exclusion criteria (Figure 4) included history of stroke or evidence of cerebrovascular disease on brain computed tomography (CT), if available, and Parkinsonism. This means that participants with dementia in our study had probable Alzheimer's disease, defined as clinical diagnosis of dementia with a lack of substantial concomitant cerebrovascular disease or core features of Dementia with Lewy bodies other than dementia itself (Parkinsonism). Performing brain imaging for all participants can be considered in future studies in order to sharpen the distinction between vascular and AD.

T-touch is probably not the optimal measurement for required stimulus duration, as tapping can be influenced by physical and psychological conditions such as fatigue, anxiety and participant preconceptions about test purpose. In addition, results may not be quantitatively applicable to other sensory modalities. Electroencephalogram (EEG) or functional brain imaging studies may yield a spatiotemporal equivalent for t-touch and lead to a more precise measurement of required stimulus duration.

The length of the geriatric assessment performed in our unit varies but usually exceeds 1 h, and this could have potentially influenced DST performance, through patient fatigue. This condition however, was the same for both control and intervention groups. Thus, if fatigue was a factor, it affected both groups equally.

Participants in both groups (intervention and control) were tested from point of DST failure. It can be argued that although close to 50% of participants improved their score on the DST in the increased digit duration paradigm (compared to approx. 5% in the control group), a detrimental effect of increased digit duration may have also been detected if both groups were started on the second DST run at a lower series length (i.e. 2). Using this refined paradigm, however, will result in an extended total DST (an addition of 4–8 more trials) and may influence performance due to patient fatigue, especially in a clinical setting of elderly participants with cognitive impairment at the end of a long geriatric assessment. Performing the DST on a separate day from the geriatric assessment may settle this issue in a future study.

Increasing digit duration to 800 ms, while maintaining a rate of one digit per second, left a 200-ms silent interval between digits. While this duration is considered to be at the upper range of the optimal silent interval for speech perception,[56] the relative contributions of stimulus duration and silent interval length require further research.

This study, conducted in the context of full geriatric assessment, employed one measure of attention and STM, the forward digit span. Addition of similar tests in future studies may add to the validity of our findings.[57]

Implications of results and future directions

The main finding in our study is that increasing stimulus duration, without change in delivery rate, led to improved performance on a test of attention and STM in cognitively impaired elderly individuals.

One possible implication and area of future research may be the application of the principle of increased stimulus duration to spoken language. This may be examined by increasing word duration in sentences without changing speech rate, similar to the method employed in this study using the DST. This approach may assist memory performance in cognitively impaired individuals and thus enhance function and communication in everyday life. The widespread availability of mobile digital devices makes computerized modification of information delivery technically feasible in a variety of settings.

As it is well known that communication deteriorates over time in people with dementia, causing distress to both patients and caregivers, an improvement in this area could be highly valuable.

The effect of increasing stimulus duration in other modalities, for example, visual, is also an area of potential interest.

Finally, the relationship between finger tapping dynamics, temporal templates of information delivery and cognitive performance in other cognitively impaired populations is also of interest, in what may be described as a search for a temporal key to attention.

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Informed consent

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