Age Effects on Sensory-Processing Abilities and Their Impact on Handwriting
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Abstract
Background. Sensory-processing abilities are known to deteriorate in the elderly. As a result, daily activities such as handwriting may be impaired. Yet, knowledge about sensory-processing involvement in handwriting characteristics among older persons is limited. Purpose. To examine how age influences sensory-processing abilities and the impact on handwriting as a daily performance. Method. The study participants were 118 healthy, independently functioning adults divided into four age groups: 31–45, 46–60, 61–75 and 76+ years. All participants completed the Adolescent/Adult Sensory Profile (AASP). Handwriting process was documented using the Computerized Handwriting Penmanship Evaluation Tool (ComPET). Findings. Age significantly affects sensory processing and handwriting pressure as well as temporal and spatial measures. Both handwriting time and spatial organization of the written product were predicted by sensory seeking. When examining age contribution to the prediction of handwriting by sensory processing, sensory seeking showed a tendency for predicting handwriting pressure (p = .06), while sensory sensitivity significantly predicted handwriting velocity. Implications. Age appears to influence sensory-processing abilities and affect daily performance tasks, such as handwriting, for which sensitivity and seeking for sensations are essential. Awareness of clinicians to sensory-processing deficits among older adults and examining their impact on broader daily activities are essential to improve daily performance and quality of life.

Abrégé
Description. Il est bien établi que les habiletés de traitement de l’information sensorielle se détériorent chez les aînés. Par conséquent, certaines activités de la vie quotidienne, comme l’écriture, peuvent être perturbées. Toutefois, les connaissances sont limitées en ce qui a trait à la façon dont le traitement de l’information sensorielle se manifeste dans les caractéristiques de l’écriture chez les personnes âgées. But. Examiner comment l’âge influence les habiletés de traitement de l’information sensorielle, de même que l’impact de l’âge sur l’écriture en tant que production quotidienne. Méthodologie. Les participants à l’étude étaient 118 adultes autonomes en santé, répartis en quatre groupes d’âges : 31 à 45 ans, 46 à 60 ans, 61 à 75 ans et 76 ans et plus. Tous les participants ont effectué le Adolescent/Adult Sensory Profile (AASP). Le processus d’écriture a été documenté à l’aide du Computerized Handwriting Penmanship Evaluation Tool (ComPET). Résultats. L’âge affecte le traitement de l’information sensorielle et la pression de l’écriture de manière significative, de même que les mesures du temps et de l’espace. Le temps d’écriture et l’organisation spatiale de la production écrite ont été prédits par la recherche de sensations. Lors de l’examen de l’influence de l’âge pour prédire les caractéristiques de l’écriture à partir des habiletés de traitement de l’information sensorielle, on a observé que la recherche de sensations avait tendance à prédire la pression de l’écriture (p = 0,06), alors que la sensibilité sensorielle a permis de prédire la vitesse de l’écriture de manière significative. Conséquences. L’âge semble avoir une influence sur les habiletés de traitement de l’information sensorielle, de même qu’un effet sur l’exécution des tâches quotidiennes, comme l’écriture, pour laquelle la sensibilité et la recherche de sensations sont essentielles. Les cliniciens doivent être conscients des troubles du traitement de l’information sensorielle chez les aînés et examiner les répercussions de ces troubles sur les activités générales de la vie quotidienne, afin de pouvoir améliorer le rendement quotidien et la qualité de vie des aînés.

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Key words
Elderly
Handwriting
Sensory processing
Task performance and analysis

Mots clés
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Écriture
Exécution et analyse de la tâche
Traitement de l’information sensorielle

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involves the registration, modulation, and internal organization of sensory input (Humphry, 2002). Deficits in processing sensory information may result in balance impairment, a reduction in visual and auditory perception, and the like, which have a negative impact on daily function (Allison, Kiimmel, & Jeka, 2006; Heine & Browning, 2002). Further, whereas most people exhibit typical sensory-processing abilities, some might have sensory-processing difficulties (SPD), that is, increased or diminished sensitivity to stimuli.

Dunn’s model (Dunn, 1997) is a prevalent model explaining the impact of SPD on performance. The model refers to the interaction between the neurological- and behavioral-response/self-regulation continuum ranging from passive to active (Dunn, 2007). This interaction yields four sensory-processing patterns: (1) low registration—individuals who fail to detect sensation and use passive behavior (low self-regulators); (2) sensation seeking—individuals who seek a rich sensory environment (high self-regulators); (3) sensory sensitivity—individuals who are distracted and feel discomfort with sensation but do not actively limit their exposure to the uncomfortable sensation (low self-regulators); (4) sensation avoiding—individuals who actively limit exposure to unpleasant sensations (high self-regulators) (Dunn, 1997). When individuals are found to be at the extreme edges of these four patterns and this affects their performance and participation, they are expressing SPD.

SPD might also exist in older persons because of anatomical and functional changes caused by aging. Disease processes that are more prevalent in older persons might also enhance this unbalanced processing. As SPD are known to negatively affect quality of life, increase accident rates, reduce life skills, and limit everyday involvement in the family and the community (Duncan & Earhart, 2011; Li-Korotky, 2012; Waters, Hale, Robertson, Hale, & Herbison, 2011), it is very important to consider SPD in older persons. Nevertheless, most studies on sensory abilities in older persons refer to sensory dysfunction in specific sensations or to sensory acuity (e.g., Allison et al., 2006; Heine & Browning, 2002) rather than to general sensory-processing abilities expressed in all sensory modalities.

Based on the above and on the rapidly increasing mean proportion of older people who wish to participate in society and maintain a good quality of life (Van Hooren et al., 2007), there is a need to further profile sensory-processing abilities in older persons and further explore their impact on daily activities.

One prevalent daily activity used along the life span is handwriting (Johansson, 2008; Rosenblum, Dekel, Gurvitz, Werner, & Heinik, 2010). Skilled handwriting is a complex activity that entails an intricate blend of cognitive, kinesthetic, and perceptual-motor components (Rosenblum, Weiss, & Parush, 2003) to which sensory processing is fundamental. For example, kinesthetic information (including light touch, discriminative touch, proprioception, and vestibular information) was found to be essential for skilled automatic handwriting and for monitoring motor performance while writing (Case-Smith, 2002). Difficulties in processing kinesthetic information might impair the autoimmunization of writing and lead to inconsistency of letter size, impaired spatial organization on the paper (Erez & Parush, 1999), greater pressure application on the pen (Feder & Majnemer, 2007), and lower stability control (Erez & Parush, 1999).

Visual information processing was also found to be critical for writing; visual perception and viso-motor integration are important for functions such as pen reaching and holding, for monitoring writing products (letter forms; writing direction), and adaptive spatial organization (Tseng & Chow, 2000).

Handwriting might be impaired by aging for several reasons, such as reduction in performance speed (Jiménez-Jiménez et al., 2011); deterioration in neuromuscular function affecting hand strength, speed, and coordination (Cole, Rotella, & Harper, 1999); object manipulation; dexterity abilities; and deficient perceptual motor abilities (Tseng & Chow, 2000), all of which are strongly associated with sensory processing. Although handwriting is one of the most performed activities in a variety of leisure and professional settings for older persons (Rosenblum & Werner, 2006) the knowledge about handwriting characteristics in older persons, as well as elements that might impair handwriting in this population, such as the involvement of SPD, is scarce.

The purpose of the present study was to explore the relationship between sensory-processing abilities and handwriting in healthy persons of varying ages. The results of this study might serve as a platform for establishing handwriting norms for healthy older adults against which the handwriting of people with pathologies can be compared. Understanding the negative consequences of functional deterioration in older persons for daily activities such as handwriting might contribute to effective care focused on improving performance in real-life settings.

Methods

Study Design
This was a comparative and correlative study based on a convenience sample.

Participants
Participants were 118 healthy and independently functioning people living in the community. All participants had been living in Israel for at least 20 years, were proficient in Hebrew (speaking, reading, and writing), had at least 12 years of education, were right-handed, and had normal vision and hearing (with or without assistive devices). Participants who reported having a chronic disease such as cancer, neurological disease, arthritis, or hypothyroidism were not included in the study. People who were taking medications affecting the central nervous system were requested to refrain from these medications on the preceding day and on the day of the test.

All participants had sufficient cognitive status and no depression symptoms or memory deficits. The participants’ cognitive status was evaluated by the Hebrew version of the Mini Mental State Examination (MMSE) (Jette, Assmann, Rooks, Harris, & Crawford, 1998; Werner, Rosenblum, Bar on, Heinik, & Korczyn, 2005) with scores ranging from 0 (total cognitive deterioration) to 30 (normal cognitive functioning). In accordance with the reported cut-off score in the literature (Tangalos, Smith, & Ivnik, 1996), participants scoring less
than 24 were excluded from the study. Exclusion criteria also included depression, as measured by the Geriatric Depression Scale (GDS) (Yesavage et al., 1983), and memory impairments, as measured by the Subjective Memory Scale (Derouesne, Lacomblwz, Thibault, & Leponcin, 1999).

The participants were divided into four groups according to age, 31–45, 46–60, 61–75, 76+ years, with 15 men and 15 women in each age group except for the oldest group, which had 14 men and 14 women.

Table 1 summarizes the means and standard deviations of age, years of education, and scores on the Mini Mental State Examination (MMSE), Geriatric Depression Scale (GDS), and subjective memory test according to age group.

### Instrumentation

**Demographic questionnaire.** This questionnaire includes data on the participant’s health status, socio-demographic status, medications, and treatments.

The Adolescent/Adult Sensory Profile (AASP) (Brown & Dunn, 2002). In this self-reporting tool, participants answer questions about their responses to sensory experiences. There are 60 items, with questions pertaining to each of the sensory systems. For scoring, the items are sorted equally into four quadrants: low registration, sensation seeking, sensory sensitivity, and sensation avoiding. Participants indicate how often they respond to the sensory event in the manner described in the items using a five-point Likert scale (from 1 corresponding to “almost never” to 5 corresponding to “almost always”). Four scores are obtained for each person (registration, seeking, sensitivity, and avoiding). The score for each quadrant ranges from 5 to 75. Norms have been defined for three age groups (11–17; 18–64; 65 and older) (Pohl, Dunn, & Brown, 2003). The English version of this questionnaire has good internal consistency (Pohl et al., 2003). To examine the validity of the translated form for this study, the questionnaire was translated into Hebrew and back translated into English by bilingual occupational therapists.

**Digitizing tablet and online data collection and analysis software.** The online computerized handwriting evaluation, called ComPET, or Computerized Pennmanship Evaluation Tool (previously referred to as POET; Rosenblum, Parush, & Weiss, 2003a), has two main parts: (1) data collection, which is language-independent and easy to use for handwriting tasks, and (2) data analysis, which was programmed with MATLAB software toolkits.

**Writing tasks.** The present study focused on writing tasks in Hebrew. Hebrew, in which all the 22 letters of the Hebrew alphabet are graphically represented, differs in several key ways from Latin-based scripts. Hebrew is written from right to left, successive letters are not connected even in script (cursive) writing, and five letters take a different form when written at the end of a word. As in other languages, some letters in the Hebrew alphabet are constructed from two separate, unconnected components or strokes.

All writing tasks were performed on A4 lined paper affixed to the surface of a WACOM Intuos 2 [model GD 0912-12X18] x-y digitizing tablet using a wireless electronic inking pen [Model GP-110]. Displacement, pressure, and pen tip angle were sampled at 100 Hz with a 1300 MHz Pentium (R) M laptop computer. The computerized system enables the collection of spatial, temporal, and pressure data while the subject is writing. The digitizer gives an accurate temporal measure for the total writing performance, both when the pen is touching the tablet and when it is in the air. The digitizer gives an accurate spatial measure when the pen is touching the tablet and when it is lifted up to 6 mm above the digitizer. Beyond 6 mm, the spatial measurement is not reliable, but the temporal measurement is.

The present study included the following writing tasks: 1. Write the alphabet sequence, which comprises the building blocks of handwriting. 2. Copy a paragraph, which provides the opportunity to evaluate prolonged writing performance.

**Kinematic measure.** Based on previous results (Rosenblum & Werner 2006; Stelmach, Goggin, & Garcia-Colera, 1987), we focused on measures of the entire task as well as measures per strokes. Measures for the entire task:

1. Mean pen velocity, as measured by centimetre per second.
2. Mean pressure implemented towards the writing surface in nonscaled units from 0 to 1,024.

In addition, five representative temporal and spatial characteristics supplied by ComPET were analyzed per strokes written on the paper.

1. Mean stroke time: The time taken to write the task divided by number of written strokes

### Table 1

<table>
<thead>
<tr>
<th></th>
<th>31–45</th>
<th>46–60</th>
<th>61–75</th>
<th>76+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>38.17 (4.55)</td>
<td>52.72 (4.55)</td>
<td>67.87 (4.76)</td>
<td>82.22 (5.03)</td>
</tr>
<tr>
<td>Years of education</td>
<td>15.85 (2.38)</td>
<td>15.34 (2.14)</td>
<td>14.58 (2.22)</td>
<td>13.51 (2.25)</td>
</tr>
<tr>
<td>MMSE</td>
<td>29.77 (0.51)</td>
<td>29.51 (0.68)</td>
<td>28.93 (1.05)</td>
<td>29.07 (0.98)</td>
</tr>
<tr>
<td>GDS</td>
<td>0.9 (1.24)</td>
<td>1.17 (1.57)</td>
<td>1.3 (1.39)</td>
<td>1.79 (1.31)</td>
</tr>
<tr>
<td>Subjective memory test</td>
<td>0.31 (0.21)</td>
<td>0.44 (0.23)</td>
<td>0.43 (0.21)</td>
<td>0.40 (0.24)</td>
</tr>
</tbody>
</table>

Note: GDS = Geriatric Depression Scale; MMSE = Mini Mental State Examination; NS = not significant; SD = standard deviation.

**Table 1**

**Mean and Standard Deviations of Age, Years of Education, Mini Mental State Examination, Geriatric Depression Scale, and Subjective Memory Test Scores**
Table 2
Estimated Means and Standard Errors of AASP Scores in Each Age Group

<table>
<thead>
<tr>
<th>Age group</th>
<th>Sensation avoiding</th>
<th>$F_{(3,112)}$</th>
<th>Sensory sensitivity</th>
<th>$F_{(3,112)}$</th>
<th>Sensation seeking</th>
<th>$F_{(3,112)}$</th>
<th>Low registration</th>
<th>$F_{(3,112)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>27–41 $^a$</td>
<td>32.73 (1.35)</td>
<td>1.48</td>
<td>33.17 (1.27)</td>
<td>1.45</td>
<td>47.75 (1.29)</td>
<td>4.57*$^a$</td>
<td>27.5 (1.02)</td>
<td>27.5 (1.02)</td>
</tr>
<tr>
<td>42–60 $^b$</td>
<td>35.46 (1.38)</td>
<td>2.04</td>
<td>36.19 (1.37)</td>
<td>2.27</td>
<td>49.66 (1.30)</td>
<td>5.88*</td>
<td>26.4 (0.97)</td>
<td>26.4 (0.97)</td>
</tr>
<tr>
<td>61–75 $^c$</td>
<td>35.63 (1.38)</td>
<td>2.04</td>
<td>36.19 (1.37)</td>
<td>2.27</td>
<td>49.66 (1.30)</td>
<td>5.88*</td>
<td>26.4 (0.97)</td>
<td>26.4 (0.97)</td>
</tr>
<tr>
<td>76+ $^d$</td>
<td>36.35 (1.38)</td>
<td>2.04</td>
<td>36.19 (1.37)</td>
<td>2.27</td>
<td>49.66 (1.30)</td>
<td>5.88*</td>
<td>26.4 (0.97)</td>
<td>26.4 (0.97)</td>
</tr>
</tbody>
</table>

Note. SE = standard error.

$^a$ Typical performance range of sensory processing for age range 18–64 years; $^b$ Typical performance range of sensory processing for age range 65+ years.

$p \leq 0.05$

2. Mean stroke width in centimetres (i.e., the width of the entire stroke on the x axis)
3. Mean stroke height in centimetres (i.e., the height of the entire stroke on the y axis)

Procedure
After the researchers received the approval of the Ethics Committee of the University of Haifa, participants were chosen as a convenience sample and, in their homes, signed an informed consent form in the presence of the data collector. In this meeting, participants filled out the demographic questionnaire and were asked five questions about their general health. Those who met the criteria were then screened with the MMSE and GDS tests and the subjective memory questionnaire and were asked to fill in the AASP and to perform writing tasks using the ComPET. All participants were examined in similar environmental conditions, in a quiet room in their own homes, with a comfortable chair and table. The participants were asked to write as they usually write every day.

Data Analysis
The differences among the groups’ sensory-processing abilities and handwriting measures were analyzed by MANOVA, while keeping education and MMSE score as a constant variable. Bonferroni’s post hoc test was used to explore the significance of the difference between groups. Linear regression examined whether age significantly predicts AASP scores as well as handwriting measures.

We then examined two questions: (1) Do AASP scores add to the prediction of writing performance above and beyond that explained by age and (2) What is the association of each measure of sensory processing after adjusting for age? For that we used hierarchical linear regression. Probabilities at or below .05 were considered significant.

**Results**

**Differences in Sensory-processing Abilities Among Age Groups**
Bonferroni’s adjustment, which was used for assessing the univariate ANCOVAs, was set at .05/4 = 0.0125 for testing the four AASP scores. MANCOVA revealed significant general differences in AASP scores between the age groups ($F_{12,313} = 4.63$, $p = 0.002$). When referring to each AASP quadrant, ANCOVA analysis following the MANCOVA found significant difference between the age group in sensation seeking ($F_{3,112} = 4.57$, $p = 0.005$).

As presented in Table 2, Bonferroni’s post hoc revealed that the eldest group showed a significantly lower tendency for sensation seeking than the age group 31–45 (Mean difference = 6.85, $p = 0.004$).

When referring to the specific modalities, MANCOVA revealed significant general differences between the age groups in seeking tendency ($F_{3,112} = 1.85$, $p = 0.01$).

ANCOVA analysis following the MANCOVA found significant differences between the age groups in the seeking tendency for tactile stimuli ($F_{3,112} = 4.1$, $p = 0.008$). The oldest age group showed a significantly lower seeking tendency for tactile stimuli than age group 31–45 (Mean difference = 2.29, $p = 0.006$).

MANCOVA also found significant difference between the age groups in the seeking tendency for activity level ($F_{3,112} = 5.88$, $p = 0.001$). The oldest age group showed a significantly lower seeking tendency for activity level than age group 31–45 (Mean difference = 2.27, $p = 0.001$).

MANCOVA also revealed significant general difference between the age groups in low registration ($F_{3,112} = 1.86$, $p = 0.02$). ANCOVA analysis following the MANCOVA found significant difference between the age groups in low registration of vestibular stimuli ($F_{3,112} = 4.21$, $p = 0.007$). The oldest age group also had significantly lower registration of vestibular stimuli than age group 46–60 (Mean difference = 1.32, $p = 0.004$).
### Table 3
Estimated Means and Standard Errors of Handwriting Velocity, Pressure, and Time in Each Age Group

<table>
<thead>
<tr>
<th>Writing assignment</th>
<th>Age group</th>
<th>Mean total velocity (cm/sec)</th>
<th>Mean stroke writing time (sec)</th>
<th>Mean stroke width (cm)</th>
<th>Mean stroke height (cm)</th>
<th>Mean pressure (0-1024 units)</th>
<th>F (SS,112)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copying a paragraph</td>
<td>31–45</td>
<td>5.23 (0.24)</td>
<td>0.21 (0.02)</td>
<td>0.23 (0.01)</td>
<td>0.37 (0.02)</td>
<td>837.93 (24.96)</td>
<td>28.41**</td>
</tr>
<tr>
<td></td>
<td>46–60</td>
<td>4.86 (0.22)</td>
<td>0.21 (0.02)</td>
<td>0.23 (0.01)</td>
<td>0.37 (0.02)</td>
<td>787.87 (23.59)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>61–75</td>
<td>4.33 (0.23)</td>
<td>0.29 (0.02)</td>
<td>0.27 (0.02)</td>
<td>0.42 (0.02)</td>
<td>762.53 (24.01)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+76</td>
<td>3.86 (0.24)</td>
<td>0.41 (0.02)</td>
<td>0.26 (0.01)</td>
<td>0.44 (0.02)</td>
<td>699.19 (25.53)</td>
<td></td>
</tr>
<tr>
<td>Writing the Hebrew alphabet</td>
<td>31–45</td>
<td>4.74 (0.25)</td>
<td>0.26 (0.06)</td>
<td>0.28 (0.02)</td>
<td>0.39 (0.03)</td>
<td>847.65 (26.35)</td>
<td>6.99**</td>
</tr>
<tr>
<td></td>
<td>46–60</td>
<td>4.41 (0.24)</td>
<td>0.24 (0.05)</td>
<td>0.26 (0.02)</td>
<td>0.38 (0.02)</td>
<td>787.79 (24.87)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>61–75</td>
<td>4.27 (0.25)</td>
<td>0.29 (0.05)</td>
<td>0.34 (0.02)</td>
<td>0.43 (0.02)</td>
<td>753.99 (25.35)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+76</td>
<td>3.46 (0.26)</td>
<td>0.56 (0.06)</td>
<td>0.29 (0.02)</td>
<td>0.44 (0.03)</td>
<td>722.47 (26.97)</td>
<td></td>
</tr>
</tbody>
</table>

**Note.** SE = standard error.
* p ≤ 0.01; **p ≤ 0.001

### Differences in Handwriting Process Measures Among Age Groups

Bonferroni’s adjustment, which was used for assessing the univariate ANCOVAs, was set at 0.05/5 = 0.01 for testing the five handwriting measures (entire task velocity, pressure, stroke time, width, and height) in each task (writing the alphabet and copying a paragraph). MANCOVA revealed significant general difference in handwriting measures between the age groups in the alphabet assignment ($F_{3,112} = 3.62, p ≤ 0.0001$).

When referring to each of the handwriting variables in the alphabet assignment, ANCOVA analysis following the MANCOVA found significant difference between the age groups in velocity ($F_{3,112} = 3.97, p = 0.01$); mean stroke time ($F_{3,112} = 6.99, p ≤ 0.0001$), and in pressure ($F_{3,112} = 3.54, p = 0.01$) (see Table 3). The oldest age group was significantly slower than age group 31–45 (mean difference = -1.28; $p = 0.007$). This was manifested in a longer stroke-writing time found in the oldest age group as compared to age group 31–45 (mean difference = -0.31; $p = 0.002$); age group 46–60 (mean difference=-33, $p ≤ 0.0001$) and age group 61–75 (mean difference = -0.27; $p = 0.003$) (see Table 3).

MANCOVA also revealed significant general difference between the age groups in the copying assignment ($F_{15,310} = 5.13, p ≤ 0.0001$). When referring to each of the handwriting variables in the copying assignment, ANCOVA analysis following the MANCOVA found significant difference between the age groups in the velocity ($F_{3,112} = 5.34, p = 0.002$); mean

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**Figure 1.** On-paper and in-air writing comparison between a representative adult aged 34 years (left) and a representative adult aged 89 years (right). The black lines represent the actual trajectory of the writer’s pen when in contact with the writing surface, and the gray lines show the in-air trajectory, that is, when the pen was above the writing surface. The temporal process variables for each of these representative participants are presented below.

**Note.** Left figure: paragraph performance time 48.87 s; stroke time on paper $M = 0.14, SD = 0.09$ s; stroke time in air $M = 0.2, SD = 0.28$ s. Right figure: paragraph performance time 235.47 s; stroke time on paper $M = 0.59, SD = 0.41$ s; Stroke time in air $M = 1.25, SD = 1.3$ s; $M =$ mean; $SD =$ standard deviation; $s =$ seconds.
stroke time ($F_{1,112} = 28.41, p \leq 0.0001$) and pressure ($F_{1,112} = 4.59, p = 0.004$) (see Table 3).

The oldest age group was significantly slower than age group 31–45 (mean difference = −1.37; $p < 0.0001$) and than age group 46–60 (mean difference = −1.01, $p < 0.0001$). The slower rate of the oldest group was manifested in longer stroke writing time (combined stroke-on-paper and in-air time). Figure 1 provides an example for stroke-on-paper and in-air time in the performance of a young versus an aged participant. This figure reflects the slower performance with growing age.

Since the velocity represents the ratio between spatial measures and time, the slower velocity with age was also manifested in stroke width and height, which increased significantly with age. However, this slower velocity was expressed only in the copying assignment, where strokes were higher among age group 76+ than in the 31–45 group (mean difference = 127.35, $p < 0.05$) (Table 3).

Pressure was also found to decrease with age. This was expressed in both assignments (alphabet sequence and paragraph copy) (see Table 3 and Figure 2).

### Table 4
Linear Regression for Predicting AASP Scores by Age

<table>
<thead>
<tr>
<th>Variables</th>
<th>$R^2$</th>
<th>$\beta$</th>
<th>SE</th>
<th>t</th>
<th>$p$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low registration</td>
<td>7%</td>
<td>0.26</td>
<td>0.03</td>
<td>2.87</td>
<td>0.005</td>
</tr>
<tr>
<td>Sensation seeking</td>
<td>17%</td>
<td>-0.41</td>
<td>0.04</td>
<td>-4.83</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Sensory sensitivity</td>
<td>4%</td>
<td>0.2</td>
<td>0.03</td>
<td>2.14</td>
<td>0.03</td>
</tr>
<tr>
<td>Sensation avoidance</td>
<td>5%</td>
<td>0.23</td>
<td>0.04</td>
<td>2.53</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Note. $R^2 = $ multiple correlation squared; SE = standard error.

### Figure 2.
Pressure levels implemented towards the writing surface by a representative adult aged 34 years (left) and by a representative adult aged 78 years (right).
β = −0.34 decreased to β = −0.30 expressing partial mediation.

While age predicted 18% (F{1,116} = 24.58, p < 0.0001) of the velocity of copying a paragraph (β = −0.42, p < 0.0001), sensory sensitivity added 3% (F{1,115} = 4.06, p = 0.04) to the prediction (β = −0.17, p = 0.04). β = −0.42 decreased to β = −0.38 expressing partial mediation. As mentioned above, age predicted 13% (F{1,115} = 17.59, p < 0.0001) of the pressure used in the copying assignment (β = −0.36, p < 0.0001), and sensory seeking added 3% (F{1,115} = 3.52, p = 0.06) to this prediction (β = −0.18, p = 0.06). However, this addition was not significant.

### Discussion

The present study explored the relationship between sensory-processing abilities and handwriting process among relatively healthy people of varying ages.

### Age and Sensory-processing Abilities

All age groups were in the typical sensory-processing performance range. Having all groups in typical performance range strengthens the ability of the AASP to profile authentically the sensory-processing patterns of typical participants. Age was found to significantly predict sensory-processing abilities as presented in all four patterns. The results of the present study, which refer to the sample’s sensory profile, strengthen the manifestation of degenerative processes of the sensory organs and tracts as well as the general degenerative processes of the brain that lead to deterioration in the ability to process sensory information (Wickremaratchi & Llewelyn, 2006).

When referring to the age groups, older people showed lower sensory-processing abilities, mainly manifested in sensory seeking and low registration—patterns related to high-neurological threshold. Pohl et al. (2003), who also used the AASP, found that adults older than 65 years noticed stimuli less than those younger than 65 years. The neural changes in older persons might lead to the need for intense sensory input to be perceived (Wickremaratchi & Llewelyn, 2006). This result should receive attention based on previous reports noting that when older people are less alert to sensation in their environment, their physical and emotional health might deteriorate (Nolan & Blass, 1992).

In the present study, age related specifically to lower seeking tendency to touch and activity level as well as lower registration of vestibular stimuli. These findings are in accordance with previous reports according to which specific sensory systems are more vulnerable to the effects of aging (Pohl et al., 2003). The deterioration in tactile seeking might relate to changes appearing in the aging skin, the decrease in the density and distribution of sensory receptors in the skin (Anstey, Luszca, Giles, & Andrews, 2001), the progressive loss of cutaneous afferent axons and skin hydration. These changes are known to influence function and performance. For example, as tactile thresholds are significantly increased, spatial acuity is decreased, and perception of texture is impaired.

Low registration of vestibular input might explain the decreased balance control and the increased likelihood of falling in older persons (Kollegger, Baumgartner, Wöber, Oder, & Deecke, 1992). Aging is known to be correlated with reduced activity level in various domains (physical, cognitive, emotional) (Thomas et al., 2009; Autenrieth et al., 2011). Based on the literature, which highlights the negative impact of reduced activity level on health and well-being, it is most important to refer to activity level in the aged population. Regarding the specific modalities, it is known that aging is related to lower motor-activity level. Age and motor-activity level affect gait, which may in turn lead to predisposition to gait-related imbalances and resultant falling (Cabel, Pienkowski, Shapiro, & Janura, 2012). Thus, it may be assumed that lower seeking tendency for somatosensory input as tactile stimuli together with lower registration of vestibular input, and their negative impact on movement/balance performance, also contribute to the lower seeking tendency for activity level, as expressed in AASP items such as “I seem slower than others when trying to follow an activity or task”; “I stay away from crowds”; “I avoid situations where unexpected things might happen.”

Based on its active strategy, the sensory-seeking pattern should receive special consideration regarding older people. Deterioration in sensory seeking has major functional outcomes, especially in the cognitive and social aspects. Both sensory and cognitive abilities have a direct influence on daily function, as expressed, for example, in speed performance (Wood et al., 2005) and efficiency (Lindenberger, Marsiske, & Baltes, 2000). Socially, deteriorated seeking might cause social dissatisfaction and even depression (Capella-McDonnell, 2005). Both of these are known to lead to dependence and lower quality of life (Fremont, 2004). Thus, intervention

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**Table 5**

**Linear Regression for Predicting Handwriting Measures by Age**

<table>
<thead>
<tr>
<th>Writing assignment</th>
<th>Variables</th>
<th>R²</th>
<th>β</th>
<th>SE</th>
<th>t</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copying a paragraph</td>
<td>Total velocity</td>
<td>18</td>
<td>−0.42</td>
<td>0.006</td>
<td>−4.96</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Total pressure</td>
<td>13</td>
<td>−0.36</td>
<td>0.68</td>
<td>−4.19</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Mean stroke height</td>
<td>10</td>
<td>0.32</td>
<td>0.001</td>
<td>3.58</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Mean stroke width</td>
<td>4</td>
<td>0.21</td>
<td>0</td>
<td>2.26</td>
<td>0.03</td>
</tr>
<tr>
<td>Writing the Hebrew alphabet</td>
<td>Total velocity</td>
<td>12</td>
<td>−0.34</td>
<td>0.007</td>
<td>−3.93</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Total pressure</td>
<td>12</td>
<td>−0.35</td>
<td>0.71</td>
<td>−3.97</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Mean stroke height</td>
<td>2</td>
<td>0.16</td>
<td>0.001</td>
<td>1.77</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Mean stroke width</td>
<td>1</td>
<td>0.11</td>
<td>0.001</td>
<td>1.16</td>
<td>NS</td>
</tr>
</tbody>
</table>

Note. NS = not significant; R² = multiple correlation squared; SE = standard error.
programs for older people should elevate their mindfulness for sensory seeking, providing strategies to enhance their involvement in life situations enriched with sensory input. In cases of deteriorated cognitive/emotional function, multifaceted training programs targeting both sensory and other related abilities are also critical for maintaining functional participation, promoting independence, and preventing functional disability (Wood et al., 2005).

**Differences in Handwriting Process Among Age Groups**

Age was found to significantly predict handwriting measures, emphasizing the deterioration in performing this activity among older persons (e.g., Carmeli, Patish, & Coleman, 2003). When referring to the age groups, it was found that, with age, writing time was longer, leading to writing slowness (as expressed in both writing assignments). This result strengthens previous studies about longer performance time among older adults (Jiménez-Jiménez et al., 2011; Rosenblum & Werner, 2006) and about general slowness related to motor and cognitive aspects (Peverly, 2006). This increased writing time might also be related to deteriorated sensory-processing abilities, which can lead to inefficiencies in viso-motor performance (Bourdin & Fayol, 1994) and deterioration in motor and cognitive performance (Lindenberger et al., 2000).

The slowness in the present study was expressed not only in the on-paper measure but also in the in-air time measure. The in-air time measure reflects maturity and automatism in performance as well as a decrease in performance as a result of pathology (Rosenblum, Parush, & Weiss, 2003a, 2003b). It can be assumed that in the present study, the increased in-air time might indicate a decrease in fluency and effectiveness of handwriting that occurs with age.

The level of pressure was also found to reduce with age, which might be the result of the decrease in hand strength of older persons and might affect writing (Rosenblum & Werner, 2006). Yet, this reduction in pressure with age was manifested only when copying a paragraph. It can be suggested that the cognitive load needed for the copying assignment (as compared to free writing measured by the alphabet list) emphasizes the impact of age on the reduced pressure. Instead of focusing on the writing process only, older persons need to concentrate also on the paragraph that they are copying; the sequence of words, their spatial position, their meaning, and so forth. Rodríguez-Aranda (2003) also reported that vocabulary skills and mental status relate to fluency performance of verbal tasks, including writing. We found that this is not only expressed in slower writing but also in motor performance related to kinesthetic input (Ranganathan, Siemionow, Sahgal, Liu, & Yue, 2001) leading to decreased pressure.

Spatial measures were found to be affected by age as expressed in increased letter size. In the very few studies about writing in normal aging, similar results were found (De La Paz & Graham, 1977). Changes occurring in manual function might reduce control of finger pinch (finger-pinch strength and steady precision finger-pinch posture) (Ranganathan et al., 2001) and, thus, lead to changes in letter size, for example. It might be suggested that the impact of age on spatial measures in the present study were found only in the copying assignment, because automatic writing, such as the alphabet, is less affected among participants with good aging. In contrast, in a copying assignment, when cognitive requirements are presented (such as attention, relation to sequence, meaning of sentences) performance is not only slower but viso-motor products, such as letters, change their characteristics. Verwey, Abrahamse, Ruitenbeek, Jiménez, and de Kleine (2011) found that among middle-aged individuals (aged 55–62) motor performance together with cognitive requirements, measured by the ability to learn movement patterns and preparing and executing integrated sequence representations, appeared to be less efficient than in young adults (aged 18–28). Practically, these results suggest that handwriting assessment (which specifically refers to slowness, pressure, and letter size) may serve as a screening tool for cognitive deterioration in the elderly. Clinicians should assess how cognitive load affects daily living activities, such as handwriting, but they should also refer to additional factors that may play a role in handwriting process and products, such as musculoskeletal function. Above all, clinicians should relate to sensory-processing abilities and understand if and how they influence cognitive or musculoskeletal abilities (Rosenblum & Werner, 2006). Further studies should examine this point in larger sample sizes of older people with and without additional disabilities and in relation to cognitive deficits.

**Predicting Activity Performance of Handwriting by Sensory-processing Abilities**

The prediction of handwriting performance by sensory-processing abilities emphasizes that unmodulated sensory-processing patterns may affect performance of daily living activities, such as writing. Nevertheless, this study shows that sensory-processing abilities have a greater relationship to handwriting performance than does age. This finding emphasizes that handwriting leans on basic mechanisms, which include sensory-processing abilities.

Yet, in a general perspective as well as when focusing on the effects of age, the association between sensory processing and handwriting was mainly manifested in the copying assignment. It may be suggested that cognitive load together with reduced ability of sensory processing might have a greater impact on performance. Trewharta, Penhune, and Li (2010) compared motor control adjustments together with cognitive load (measured by conflict adaptation) among younger and older adults. Older adults spent less time planning and more time executing their responses than the younger participants.

Whereas studies about slower performance time in older people discussed motor and cognitive aspects (e.g., Wood et al., 2005), the present study emphasized the contribution of sensory-processing difficulties to this slowness and provides another perspective that strengthens studies referring to neural changes in older persons that cause slowness. For example, Marchand et al. (2011) explained that declining motor control and function in normal human aging is associated with changes in the cortico-basal ganglia circuitry affecting subcor-
tical nuclei as well as cortical motor and sensory regions.

When referring to the ability of sensory-processing patterns to predict handwriting measures, seeking was found to play a major role—it significantly predicted writing time and stroke width. However, when exploring the contribution of age to this prediction, time performance (or copying velocity) was significantly related to sensory sensitivity. The ability of seeking tendency to predict handwriting pressure was close to significance. It may be suggested that in a larger sample, or in a sample of older adults with pathologies, this prediction will prove to be significant. Thus, this result should be interpreted. The meaning of seeking tendency in older adults, together with sensory sensitivity for activity performance, should receive special attention in research and practice.

Reduced sensory input may result from impaired registration or reduced sensitivity, which may lead to reduced seeking. When this reduction occurs in regard to kinesthetic information, it might be expressed in slower writing and unmodulated pressure on the pen (Erez & Parush, 1999).

The study results also showed that individuals with greater sensory-seeking tendency not only wrote faster and used more pressure, but showed more adequate proportion of letter size. This finding supports previous reports about handwriting (e.g., Tseng & Murray, 1994) as well as about neural mechanisms of aging, which also highlight the interaction between motor performance and sensory function (Li-Korotky, 2012; Waters et al., 2011). The present study emphasizes the findings of these studies as manifested in handwriting, which is a daily task performed across the lifespan.

Practically, encouraging older adults to be more sensitive to their environment and actively seek out sensations may be crucial for their performance. Clinicians should refer to the interaction between the person’s body functions (as motor, sensory, cognitive abilities), analyze his or her ability to perform and participate in daily activities, and understand the person’s preferences for participating in activities and the environments in which the person participates. Then, based on the person’s preferences or environments in which he or she performs and participates, clinicians should identify opportunities for enriching sensory input and enhance the tendency for seeking sensory information. For example, elevating awareness of the need to actively search for sensory input among older adults and their families encourages participation in community activities, including socializing, exercising, and in writing groups or other activities, such as making lists of groceries, daily errands, or future plans.

Limitations and Research Recommendations

First, this study was based on a convenience sample that included relatively few participants in each age group. Second, this study referred to healthy, independent participants. Third, handwriting was in the Hebrew language and, therefore, results may not apply to English or to other languages. Thus, it is recommended to further study the role of age as a mediator between sensory-processing abilities and handwriting and to provide strategies to enhance older adults’ participation in handwritten tasks. This analysis should be performed on larger samples and in populations with disabilities involving cognitive impairments (such as Alzheimer’s disease) or changes in emotional status (such as depression). These further studies may enable generalization of the results and elaborate our knowledge about typical performance as compared to impaired performance in populations of specific ages.

Conclusion

In general, greater tendency for sensation seeking was related to better handwriting performance as expressed in temporal and spatial measures. However, when referring to age as a mediator between sensory-processing abilities and handwriting, sensory sensitivity seems to contribute to handwriting velocity and sensation seeking may be significant for handwriting pressure.

The meaning of the seeking tendency, together with sensory sensitivity for activity performance in older adults, should receive special attention in research and practice.

Since sensory-processing abilities might be affected by age and influence daily performance tasks such as writing, it is essential that clinicians be aware of the sensory-processing deficits among older adults and examine the impact of these deficits on broader daily activities. To improve the daily performance and quality of life of older adults, clinicians should identify opportunities for enriching sensory input and enhance the tendency for seeking sensory information.

It is necessary to screen for sensory-processing deficits among older adults by referring to all sensory modalities. In addition, there is a need for early screening of functional signs by using a daily activity. This study found handwriting as an activity that is useful for exploring the impact of age on sensory-processing abilities. The ComPET was found to be sensitive for this purpose. This screening may inform training programs aimed at improving sensory-processing performance in real-life settings and assist older people to participate in society and elevate a good quality of life.

Key Messages

- Sensory-processing abilities might be affected by age and influence daily performance tasks, such as writing.
- It is essential to screen for sensory-processing deficits among older adults in light of their expressions in daily life activities.
- Early screening may enhance training programs to improve performance in real-life settings.

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