Article

Development of an Ergonomic Writing Assistive Device for Finger Pain Reduction in the Elderly

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Abstract: The decreased muscle mass and increased prevalence of musculoskeletal diseases in the elderly means that this population often experiences difficulty with writing. Although various commercial writing assistive devices exist to reduce pain and improve writing efficiency, low satisfaction with their design prevents them from being widely adopted. In this study, we developed a new ergonomic writing assistive device that overcomes these shortcomings and reduces finger pain. Twenty elderly people with normal writing skills participated in a performance evaluation of our designed device. We used two commercial writing assistive devices and the developed writing assistive device to write a given experimental sentence three times each for each device. For each device, finger-related muscles activity and finger pressure were measured during the experiment, and satisfaction level was evaluated using the modified QUEST 2.0 after the experiment. As a result, the activity in abductor pollicis brevis (18.16%) and first dorsal interosseous muscle (14.17%) was significantly higher when using the NDWAD (newly developed writing assistive device) than when using commercialized WADs (writing assistive devices) (p < 0.05). Finger pressure in the thumb (0.59 N), index finger (1.09 N), and middle finger (0.46 N) was significantly lower when using ND-WAD than when using WADs (p < 0.05). The satisfaction level of NDWAD (4.47) was higher than that of WADs. Therefore, we confirmed that our design reduced finger pressure and improved user satisfaction. Consequently, the NDWAD developed in this study can be used as a writing aid not only for the elderly, but also for patients with writing disabilities.

Keywords: writing assistive device; electromyography; finger pressure; satisfaction; muscle activity

1. Introduction

Today, literacy skills are required to adapt to a rapidly changing social environment. Literacy refers to the ability to read and write, but it is so important that it is essentially required for participation in social and cultural life [1]. In Korea, adult literacy education is provided to improve literacy skills. According to the National Institute for Lifelong Education and KOSIS (Korean Statistical Information Service), the elderly in their 60s and older comprise 95% of the illiterate population and 87% of the participants are in literacy education [1,2]. The writing activity of literacy education can have a positive effect on cognitive function, depression, and social network in the elderly [3,4]. However, as a consequence of aging, the body loses muscle strength and grip strength as muscle mass decreases [5,6], and pain in muscles and joints increases along with the presence of musculoskeletal diseases [7], making writing more difficult. In an experiment comparing young adults and the elderly, the elderly took longer to write [8]. A slow writing speed lengthens writing time, and may cause excessive muscle contraction, resulting in pain [9].
The elderly sometimes use WADs (writing assistive devices) to reduce muscle pain in their fingers that can occur after writing for a long time. Existing WADs, however, have a weak holding power of the pen, which reduces writing efficiency. Furthermore, existing WADs actually increase the burden on other muscles (wrist, shoulder, and waist), making it difficult to write for a long time [10,11].

Previous studies that conducted device development and performance evaluation to solve and improve the problems of existing WADs are as follows. Sohn and Yang derived and developed design guidelines for WADs for children with crippled disorder [12]. Comparing the performance of their WAD against a normal pen, it was reported that, although writing accuracy improved, some children found it difficult to use because of the unfamiliar grip method, shape, and the uniform size of WADs. Dyer studied the potential use of a WAD for the elderly with osteoarthritis of the hand [13]. A new WAD used in this research had excellent pen fixing power as the pen and the assistance device were manufactured integrally. Additionally, the internal structure of this WAD, which is wrapped in latex, is made of vacuum powder, so it can be adjusted to suit the hand of the user. However, as a result of comparative experiments, the writing speed was slower when using the new WAD than the commercialized WAD. In addition, it was confirmed that there are disadvantages in comfort and durability compared with the commercialized WAD. Especially, in some cases, the pen was damaged during use owing to the weak durability of the manufacturing material. Taş et al. developed a personalized WAD for patients with writer’s cramp [14]. Using their WAD, writing ability was improved compared with normal pens. Additionally, in a previous study on the WAD design elements for people with spinal disorders, it was found that improvements such as grip method, shape, size, fixation power, and material were necessary [11].

We learned from previous studies that, when designing a WAD, the grip method, shape, size, durability, and shape of the finger should be considered. Moreover, in evaluating the usability of a WAD, the previous studies evaluated only subjective indicators such as writing accuracy, preference, and comfort. However, we also found that the biomechanical properties of the muscles of the hand and arm must be considered when using a WAD. Therefore, in this study, an ergonomic WAD was developed that solved the limitations of existing studies, and the usability of various subjective viewpoints was evaluated using QUEST 2.0 (Quebec User Evaluation of Satisfaction with Assistive Technology). In addition, to evaluate the biomechanical properties applied to the muscles of the hand and arm when using a WAD, muscle activity and finger pressure distribution were measured.

In this study, we designed and developed a new WAD that reduces finger pain in consideration of ergonomic elements. The grip method of the NDWAD (newly developed writing assistive device) improves on the widely-used dynamic-tripod grip. In order to reduce the pain caused by pressure concentration on the fingertips while holding the writing implement, it was designed ergonomically through 3D modeling in consideration of the curvature of the fingers to distribute the pressure. TPU (thermoplastic polyurethane) was used as a material to improve fixing power and durability. We also studied lightweight materials to reduce the burden on finger-related muscles and the appropriate size to improve its suitability for use with a diverse range of people with hands of various sizes. As a result, the weight of the NDWAD was reduced by adjusting its internal density, and manufactured using a 3D printer after measuring the size of the hands of men and women. We hypothesized that an ergonomically designed NDWAD would be effective in improving pain and satisfaction. In order to compare and evaluate the performance of the NDWAD, two of the existing WADs with similar grip methods or functions were selected and used in a handwriting experiment. During the writing experiment, muscle activity and finger pressure were measured using a scale related to muscle pain and load [15–19]. After the experiment, we used the QUEST 2.0 questionnaire modified to fit the WAD to evaluate satisfaction [20].
2. Materials and Methods

2.1. Participants

All participants were recruited from the K senior welfare center located in J city, Republic of Korea. The participants consisted of 20 elderly people 65 years of age or older who had no experience in using WAD and had the cognitive ability to follow the researcher’s instructions (without brain-related disease), as shown in Table 1. In addition, there should be no finger impaired, and no musculoskeletal disorders in the upper extremities in order to measure their muscle activity and finger pressure. The purpose and method of the experiment were explained to the participants, and the experiment was conducted after obtaining each participant’s signature on a consent form.

| N = 20 | Sex | Age       |
|------|-----|----------|
| 6    | Male| 78.5 ± 0.9 |
| 14   | Female| 77.9 ± 3.2 |

2.2. Design of Writing Assistive Device

The grip method of the NDWAD used a dynamic tripod grip (the most popular one). The dynamic tripod grip is a writing method of holding the pen between the thumb and the index finger, placing the pen in the center of the middle finger (or distal phalanx of the middle finger), as shown in Figure 1a. As shown in Figure 1b, the NDWAD is designed to distribute finger pressure by allowing the ring finger and little finger, which are not normally involved in pen grip, to assist the main fingers (thumb, index finger, and middle finger) involved in writing. So, to prevent pressure from being concentrated on the area in contact with the writing instrument, a prototype NDWAD was designed to be comfortable to use while distributing force across the entire hand. Based on the prototype shape in Figure 1b, the overall shape of the NDWAD was designed through 123D Design (Autodesk, Inc., San Rafael, CA, USA).

![Figure 1](image-url)  
**Figure 1**. Ergonomic design of the WAD: (a) existing dynamic-tripod grip and (b) improved dynamic-tripod grip using a prototype NDWAD.

In this paper, as shown in Table 2, after measuring the hand sizes (hand length, middle finger length, and palm width) of each male and female participant, the average value was taken and two types of initial shape were conceived, as shown in Figure 2a. As shown in Figure 2b, while testing the feeling of use of the initial model, the entire edge was filleted and modified. The overall shape was averaged by increasing the degree of freedom without designating the tips of the fingers except for the thumb so that the length of each individual’s finger was not significantly affected. In the final form, the contact area between the hand and the NDWAD was increased so that the user can take notes while holding the NDWAD as if it were wrapped around it, as shown in Figure 2c.
Table 2. Satisfaction items for the WAD evaluation instrument.

| Gender | Hand Length | Middle Finger Length | Palm Width |
|--------|-------------|-----------------------|------------|
| Male   | 18.82 ± 0.69 | 8.27 ± 0.56           | 8.90 ± 0.60 |
| Female | 17.29 ± 0.77 | 7.43 ± 0.37           | 8.13 ± 0.44 |
| Mean   | 18.05 ± 0.73 | 7.85 ± 0.47           | 8.51 ± 0.52 |

Figure 2. 3D modeling in the NDWAD: (a) initial design stage; (b) detail correction stage; and (c) final stage.

TPU was selected as the material for manufacturing the NDWAD. TPU is less prone to injury due to its soft nature, and its surface characteristics improve the NDWAD’s pen holding power and prevent it from slipping out of your hand. Moreover, its higher elasticity and durability properties protect against deformation that may occur when using the NDWAD for a prolonged time. Although the NDWAD is larger than other writing aids, it has a good grip and is light in weight. The weight of our NDWAD was reduced to less than 30 g by adjusting its internal density while maintaining its external strength.
using an FDM 3D printer. The NDWAD can be produced in various sizes through a simple scale adjustment to the 3D printer, making it possible to create a personalized WAD for each user.

2.3. Experimental Tools (WADs)

As shown in Table 3, size S was designed to be suitable for female participants while size M was designed to be suitable for male participants of the NDWAD. SW (Steady Write®) and WB (Writing Bird™), which are commercial WADs that can be used by the elderly, were selected for comparative evaluation of the NDWAD’s performance. The reason for the selection is that SW has a similar grip method and WB has similar functions in terms of pressure dispersion. As SW and WB are sold in a single size, only one size of both existing WADs was used in this study.

Table 3. Experimental tool information.

| Name       | SW          | WB          | NDWAD       |
|------------|-------------|-------------|-------------|
| Figure     |             |             |             |
| Weight (g) | 30.0        | 170.1       | 24.6 (S)    |
| Size (mm)  | 63.5 × 50.8 × 11.43 | 146.1 × 63.5 × 38.1 | 90.5 × 43.5 × 62.3 |
|            |             |             | 97.5 × 48.2 × 67.6 |
| Feature    | Similar to dynamic tripod grip, triangle bottom surface. | Similar to mouse grip, flat bottom surface. | Dynamic tripod grip improvement, ergonomic design. |
| Model name | Steady Write | Writing Bird | -           |
| Manufacturer | Maddak, Inc., Wayne, NJ, USA | North Coast Medical, Inc., Morgan Hill, CA, USA | - |
| Material   | HIPS plastic (hard) | Acrylic (hard) | TPU (soft) |

2.4. Experimental Procedure

The participants performed a written experiment by rewriting the prepared experimental sentences three times using each of the three types of WADs (nine times in total) while sitting in the assigned seat. The experimental sentence was “아름다운 동물 날의 빛 풍경 (a beautiful sunlight landscape at dawn)”, which contains the Hangul consonants “ㄱ~ㅎ”. To prevent the order in which WADs were used from affecting the study results, use was randomized, with a break of 5 min provided after each use. The pain assessment scale was measured using a Noraxon Desktop DTS system (Noraxon, Inc., Scottsdale, AZ, USA) after attaching an sEMG (surface electromyography) sensor to the APB (abductor pollicis brevis), FPL (flexor pollicis longus), FDI (first dorsal interosseous), EIP (extensor indicis proprius), FCR (flexor carpi radialis), and ECRB (extensor carpi radialis brevis) (Figure 3). The measured muscle activity was filtered using a sampling rate of 1000 Hz, a 80 to 250 Hz band-pass filter, and a 60 Hz notch filter after signal amplification. To reduce the difference in muscle signal volume between participants, the MVC (maximum voluntary contraction) of each muscle area used in the experiment was measured and normalized using it.
Figure 3. sEMG sensor position. 

For additional handwriting pain evaluation, a pressure sensor FSR-400 (Interlink Electronics, Inc., Camarillo, CA, USA) was attached to the contact surface between the WAD and the finger to measure the pressure of each of the thumb, index finger, and middle finger, which are mainly used for writing, as shown in Figure 4. The analog signal of the pressure sensor was collected at 50 Hz using Arduino Uno and converted into Newton (N) units through coding.

Figure 4. Pressure sensor position of the WADs: (a) pressure sensor and (b) the appearance of a pressure sensor attached to each WAD.

One-way ANOVA and Kruskal–Wallis tests were performed using SPSS 12.0 (IBM, Corp., Chicago, IL, USA) to compare differences between muscle activity and finger pressure across WADs. To verify significance, the statistical significance level was set at $p < 0.05$.

2.5. Satisfaction Evaluation

To compare differences in satisfaction between the SW, WB, and NDWAD, we used a modified QUEST 2.0. The evaluation criteria consisted of nine items, as shown in Table 4. Among the eight items (device section) of the existing QUEST 2.0, the ‘Adjustments’ item that did not fit the WAD evaluation was deleted, and the ‘Use again’ and ‘Recommendation’ criteria were added instead.
Table 4. Satisfaction items for WAD evaluation instrument.

| No. | Satisfaction Assessment Item          |
|-----|--------------------------------------|
| 1   | Dimension                            |
| 2   | Weight                               |
| 3   | Safety                               |
| 4   | Durability                           |
| 5   | Easy to use                          |
| 6   | Comfort                              |
| 7   | Effectiveness                        |
| 8   | Use again                            |
| 9   | Recommendation                      |

The score for the items in the satisfaction evaluation was assessed using a five-point Likert scale (from 1 = ‘not satisfied at all’ to 5 = ‘very satisfied’). The importance survey of QUEST 2.0 (modified version) was conducted such that the respondent selected three of the nine items that they considered to be the most important. When a low score was recorded among the satisfaction scores, users were prompted to provide specific reasons in the opinion column. These responses were analyzed in the qualitative evaluation. The satisfaction questionnaire was then statistically analyzed using SPSS 12.0. Statistical methods were the Kruskal–Wallis test and Chi-square test. To verify statistical significance, the significance level was set at $p < 0.05$.

3. Results

3.1. Performance Evaluation

3.1.1. Muscle Activity

Table 5 and Figure 5 show the measurement results of upper extremity muscle activity according to the use of WADs. In APB and FDI, muscle activity significantly decreased when using WB compared with NDWAD and SW ($p < 0.05$), but there was no significant difference between NDWAD and SW. In addition, there was no difference in muscle activity according to the use of three types of WADs in FPL, EIP, FCR, and ECRB.

Table 5. Muscle activity associated with the use of each WAD.

| Muscle Activity (%) | SW  | WB  | NDWAD | F   | $p$   | Post-Hoc (Tukey) |
|---------------------|-----|-----|-------|-----|-------|------------------|
| APB                 | 19.05 | 10.25 | 18.16 | 6.14 | 0.004* | b < a, c         |
| FPL                 | 14.19 | 14.70 | 18.03 | 1.69 | 0.196  |                  |
| FDI                 | 16.38 | 8.73  | 14.17 | 11.46| 0.000* | b < a, c         |
| EIP                 | 13.73 | 14.00 | 12.94 | 0.16 | 0.856  |                  |
| FCR                 | 8.65  | 10.20 | 8.97  | 0.61 | 0.546  |                  |
| ECRB                | 29.79 | 29.13 | 30.52 | 0.11 | 0.899  |                  |

$p < 0.05$, a: SW, b: WB, c: NDWAD.

Figure 5. Mean muscle activity of the hand and wrist.
3.1.2. Finger Pressure

Table 6 and Figure 6 show the finger pressure applied to each WAD. In the finger pressure results, SW had the highest-pressure value on the thumb and index finger, while WB had the highest-pressure value on the middle finger. NDWAD had the lowest pressure value across all fingers. The difference in finger pressure results across WAD types was significant ($p < 0.05$).

Table 6. Finger pressure associated with the use of each WAD.

| Finger Pressure (N) | SW | WB | NDWAD | F    | $p$    | Post-Hoc (Tukey or Mann Whitney U) |
|--------------------|----|----|--------|------|-------|----------------------------------|
| Thumb              | 2.48 | 1.35 | 0.59   | 29.06 | 0.000* | c < a, b, c < b < a               |
| Index finger       | 2.07 | 1.35 | 1.09   | 12.42 | 0.002* | b, c < a                         |
| Middle finger      | 0.59 | 1.25 | 0.46   | 13.30 | 0.000* | b < a, c                         |

$* p < 0.05$, a: SW, b: WB, c: NDWAD.

Figure 6. Mean pressure of finger.

3.2. Satisfaction Evaluation

Table 7 summarizes the values of each item for Cronbach’s alpha prior to the satisfaction evaluation of each WAD. As a general matter, no problem with reliability exists if the value is greater than 0.7. In this study, the Cronbach’s alpha value was 0.858, confirming that reliability was high, and that the responses to the satisfaction evaluation had high internal consistency. In addition, the fact that the Cronbach’s alpha value of each item is similar to the average means that the correlation is high, and the results of all items can be used for analysis without deletion.

Table 7. Satisfaction evaluation item reliability assessment (Cronbach’s alpha).

| Item               | Cronbach’s Alpha |
|--------------------|------------------|
| Dimension          | 0.853            |
| Weight             | 0.860            |
| Safety             | 0.855            |
| Durability         | 0.859            |
| Easy to use        | 0.825            |
| Comfort            | 0.832            |
| Effectiveness      | 0.826            |
| Use again          | 0.827            |
| Recommendation     | 0.838            |
| Cronbach’s alpha   | 0.858            |

Item: question items for satisfaction evaluation.
Table 8 and Figure 7 show the evaluation results of nine questions relating to satisfaction levels. In the SW section, ‘Weight’ and ‘Safety’ had the highest score, and ‘Recommendation’ had the lowest score. In WB, ‘Safety’ had the highest score, while ‘Easy to use’ and ‘Recommendation’ had the lowest. For the NDWAD, ‘Dimension’, ‘Safety’, and ‘Durability’ received the highest scores, while ‘Recommendation’ received the lowest. The mean satisfaction score for all items was NDWAD (4.47), SW (3.99), and WB (3.29). There was a significant difference ($p < 0.05$) in ‘Easy to use’, ‘Comfort’, ‘Effectiveness’, ‘Use again’, and ‘Recommendation’ among the nine items.

Table 8. WAD satisfaction.

| Items             | SW Mean ± SD (Range) | SW Mean ± SD (Range) | NDWAD Mean ± SD (Range) | Chi-Square | $p$  |
|-------------------|----------------------|----------------------|-------------------------|------------|------|
| Dimension         | 4.65 ± 0.88 (2–5)    | 4.15 ± 1.42 (1–5)    | 4.90 ± 0.45 (3–5)       | 4.83       | 0.089|
| Weight            | 4.80 ± 0.52 (3–5)    | 4.55 ± 1.05 (1–5)    | 4.85 ± 0.49 (3–5)       | 0.92       | 0.631|
| Safety            | 4.80 ± 0.52 (3–5)    | 4.60 ± 1.05 (1–5)    | 4.90 ± 0.45 (3–5)       | 1.25       | 0.534|
| Durability        | 4.70 ± 0.80 (2–5)    | 4.65 ± 0.88 (2–5)    | 4.90 ± 0.45 (3–5)       | 1.30       | 0.522|
| Easy to use       | 3.45 ± 1.36 (1–5)    | 2.10 ± 0.91 (1–4)    | 4.40 ± 0.82 (3–5)       | 26.89      | 0.000 *|
| Comfort           | 4.00 ± 1.21 (2–5)    | 3.05 ± 1.64 (1–5)    | 4.30 ± 0.92 (3–5)       | 7.23       | 0.027 *|
| Effectiveness     | 3.50 ± 1.32 (1–5)    | 2.15 ± 1.23 (1–5)    | 4.10 ± 1.17 (1–5)       | 18.88      | 0.000 *|
| Use again         | 3.25 ± 1.33 (1–5)    | 2.25 ± 1.25 (1–5)    | 4.10 ± 1.25 (1–5)       | 15.78      | 0.000 *|
| Recommendation    | 2.80 ± 1.13 (1–5)    | 2.10 ± 1.07 (1–5)    | 3.75 ± 1.29 (1–5)       | 15.072     | 0.001 *|

Mean satisfaction 3.99 ± 0.51 (1.78–5.00) 3.29 ± 0.58 (1.11–4.89) 4.47 ± 0.40 (2.33–5.00)

SD: standard deviation; Range: min–max; $^*$ $p < 0.05$.

**Figure 7.** Satisfaction of each WAD ($^*$ $p < 0.05$).

When participants were asked to select the three most important questions among the WAD satisfaction evaluation questions, ‘Comfort’ took first place (appearing 16 times (26.67%)), ‘Effectiveness’ took second place (appearing 13 times (21.67%)) and ‘Easy to use’ took third place (appearing 10 times (16.67%)) (Table 9).
Table 9. WAD factor importance.

| Item           | N (%)  | Ranking |
|----------------|--------|---------|
| Dimension      | 4 (6.67) | 7       |
| Weight         | 0 (0.00) | 8       |
| Safety         | 5 (8.33) | 6       |
| Durability     | 0 (0.00) | 8       |
| Easy to use    | 10 (16.67) | 3     |
| Comfort        | 16 (26.67) | 1     |
| Effectiveness  | 13 (21.67) | 2     |
| Use again      | 6 (10.00)  | 4       |
| Recommendation | 6 (10.00)  | 4       |

N: The number of people who chose each item; ranking: ranks with high importance (%).

The qualitative evaluation of interview answers related to satisfaction, as shown in Table 10, the complaint proportion of WB is high in the order of WB, SW, and NDWAD.

Table 10. Qualitative evaluation of each WAD.

| Complaint    | SW | WB | NDWAD |
|--------------|----|----|-------|
| Dimension    | 5% | 15%| -     |
| Weight       | -  | 5% | -     |
| Safety       | -  | 5% | -     |
| Durability   | 5% | 5% | -     |
| Easy to use  | 30%| 65%| -     |
| Comfort      | 15%| 40%| -     |
| Effectiveness| 25%| 70%| 5%    |
| Use again    | 35%| 60%| 10%   |
| Recommendation| 40%| 65%| 15%   |

~%: those who have complaints/participants (20 people) × 100.

4. Discussion

An ergonomic WAD was developed to reduce finger pain for the elderly by improving the fixing power, grip method, material, size, and weight of existing WADs. In order to confirm the effectiveness of the NDWAD, a handwriting experiment was conducted, comparing it to the existing WADs SW and WB. Muscle activity and finger pressure generated during the handwriting experiment were measured, and after the experiment, the satisfaction level associated with the use of each WAD was investigated through modified version of the QUEST 2.0 questionnaire.

Among the measured average muscle activity results of the hand and wrist, we noted significant differences in APB related to thumb abduction and FDI related to abduction/adduction and flexion of the index finger. Both APB and FDI were the lowest in WB, while SW and NDWAD showed similar muscle activity. The NDWAD was designed to be used as the dynamic tripod grip, which is the most popular grip method. The SW can also be used in the dynamic tripod method. It can be confirmed that the developed NDWAD was properly designed because the muscle activity was similar when using SW and NDWAD based on the same grip method. In addition, in this study, it was determined whether the shape and grip method of the WAD affect the muscle activity related to writing. In WB, the activity of APB and FDI was significantly decreased compared with SW and NDWAD. SW and NDWAD use a dynamic tripod grip with a lot of thumb and index finger movement, while WB uses a grip similar to holding a computer mouse. From these results, it was confirmed that the shape and grip method of the WAD affect the muscle activity.

Although the activity of FPL involved in thumb flexion was not significant, it was highest in the NDWAD, and similar muscle activity was shown in SW and WB. It is suggested that this difference in muscle activity occurred as a result of the continuous flexion of the thumb as the NDWAD design considering the flexion and position of the thumb. No significant difference in the results of each WAD was found for EIP involved in index finger.
extension, FCR, and ECRB involved in wrist bending and stretching. This means that these muscles are constantly activated without being affected by the shape and type of WAD. A previous study reporting on the relationship between writing and muscle activity also found that muscle activity related to wrist movement was stably maintained even as grip method changed [21,22]. Therefore, in order to investigate the correlation between grip method and muscle activity, it is necessary to additionally investigate not only muscles related to wrist movement, but also other upper limb muscles such as the biceps brachii and trapezius [23–26].

In the mean of finger pressure results, SW had higher results in the thumb and index finger compared with other WADs, while WB showed the highest result in the middle finger. The NDWAD was associated with the lowest finger pressure overall. The NDWAD is made of soft TPU, so it disperses pressure, but SW and WB are all hard, so pressure cannot be dispersed. We also hypothesize that the shape of the NDWAD, which was designed for the flexion of the hand, helped distribute and reduce pressure. The NDWAD showed similar values to SW in muscle activity, but the thumb and index finger pressures were significantly lower than SW. It can be concluded that the NDWAD is better than SW in terms of finger pressure reduction. It is clear that the muscle activity results are highly correlated with the grip method of WADs, but the finger pressure results are highly correlated with the material (hardness) and shape of the WAD, as opposed to grip method. Existing WADs are not finger-tailored, and as only a single size is manufactured, it was not possible to provide customized sizes suited to use by both male and female participants. In the experiment, as only the NDWAD provided two sizes considering the size of the finger (male and female), it can be determined that not only the physical properties of each WAD but also the size factor helped reduce the pressure. The NDWAD, developed through a 3D printer, could provide customized WADs, but for the smooth progress of the experiment, the experiment was conducted using only women’s S and men’s M sizes. Considering that personalized assistive devices manufactured with a 3D printer have shown positive effects in previous studies [27–30], further finger pressure reductions are to be expected if personalized NDWADs are used in the experiment.

As shown in the radar chart in Figure 7, the NDWAD showed the highest satisfaction in all items, followed by SW and WB. There were significant differences in the ‘Easy to use’, ‘Comfort’, ‘Effectiveness’, ‘Use again’, and ‘Recommendation’ assessments. Differences in ‘Dimension’, ‘Weight’, ‘Safety’, and ‘Durability’ were not significant. In terms of ‘Dimension’ satisfaction, as only one size was produced for SW and WB, we expected that the NDWAD, which provided two sizes, would show a statistically significantly higher satisfaction level. Ultimately, however, we found that the difference in dimension satisfaction was insignificant. This is because, unlike the NDWAD, where the position of the fingers is fixed to some extent considering the curvature of the fingers, SW and WB do not have detailed positions, so they can be used even if the size does not match. In terms of ‘Weight’ satisfaction, NDWAD and SW were particularly similar, while WB showed relatively low satisfaction. During the experiment, users seemed to highly appreciate the lightness of NDWAD and SW, as opposed to the heaviness of WB. Nevertheless, the reason there is no significant difference is that the shape of the WB (large area in contact with the paper) can disperse the weight, so the weight burden may have been low, except when the user changes paper. The reason for the insignificant differences in results across the ‘Safety’ and ‘Durability’ assessments seems to be that each WAD has a relatively simple shape or structure and is made of materials that are not easily destroyed or threatened.

The WB, with its unfamiliar grip method, received a low satisfaction score in the ‘Easy to use’ item, while SW and NDWAD, which used relatively familiar dynamic-tripod grips, received higher scores. In terms of ‘Comfort’ satisfaction, the relatively hard and heavy WB received the lowest score. The hard but light SW received the second highest satisfaction score, and the soft and light NDWAD received the highest. It is likely that factors such as material and weight are reflected in the evaluation score. The results of the ‘Effectiveness’ item appear to have changed depending on the presence or absence of ergonomic design.
The ergonomic design considering the shape and curvature of the hand, the two sizes provided depending on the size of the hand, and the frictional properties of the TPU used as a material allowed the participants to grip the NDWAD well. For SW and WB, in contrast, as the position of the hand is not fixed, the position of the hand slightly changes each time writing, making it difficult to obtain a stable grip, lowering the satisfaction of reflected in the ‘Effectiveness’ evaluation. In addition, because, in terms of ‘Use again’ satisfaction being similar to ‘Effectiveness’, it is considered that there is a tendency to want to use the WAD again, which felt effective in writing. The result of the ‘Recommendation’ item was similar to the result received by each WAD in other items, but it showed the lowest score among all items. Participants assumed a situation in which they recommended the WAD to their acquaintances, so it is considered that the score was obtained due to more careful evaluation.

There was a significant difference in how the users evaluated the importance of the ‘Easy to use’, ‘Comfort’, ‘Effectiveness’, ‘Use again’, and ‘Recommendation’ items. It can be seen that, the difference in satisfaction evaluation scores according to the WAD was larger as the satisfaction items that the participants (elderly) considered important were greater. And, the items that were significant in the results became important criteria for determining actual users’ satisfaction. In addition, there were many complaints about these items in the qualitative evaluation, which means that, the more important the item is, the more active it tends to answer the complaints. Among these five items, 40–70% of users commented on inconveniences or problems after using WB (which received the lowest overall satisfaction score), while only 15–40% commented after using SW (which received the second lowest score). The NDWAD received relatively few complaints. Of the comments received, 5% related to ‘Effectiveness’, 10% related to ‘Use again’, and 15% related to ‘Recommendation’. These qualitative evaluation results confirmed that the NDWAD received positive reviews in the ‘Easy to use’ and ‘Comfort’ items, which were more important to users than SW and WB. There were few complaints received relating to other items that were not significant.

Overall, the NDWAD had similar muscle activity to SW, but the NDWAD is better in terms of finger pressure and satisfaction evaluation score. WB was better than the NDWAD in terms of muscle activity, but the NDWAD is better in terms of finger pressure and satisfaction evaluation score. As a result of a comprehensive analysis of muscle activity, finger pressure, and satisfaction evaluation scores, it can be concluded that the NDWAD is relatively better than SW and WB.

5. Conclusions

Age-related muscle loss, weakness, and pain can negatively affect the ability to write. WAD can be used to solve these problems and help users to write long sentences, but previously developed WADs can cause muscle fatigue and pain when used over a long period, as a result of problems such as weak fixation, unfamiliar grip, too hard materials, limited size, and high weight. We thus developed a NDWAD that employed 3D design and 3D printer and accounted for ergonomic factors to overcome these shortcomings. The NDWAD, compared against two existing WADs (SW and WB), requires less overall muscle activity and finger pressure than SW, which uses a dynamic tripod grip, and lower finger pressure than WB, which employs a different grip method. NDWAD users also expressed higher satisfaction with the new design than with existing SW and WB across all nine satisfaction criteria. In sum, the NDWAD was helpful in reducing fatigue and pain. Our design, which may be personalized to specific hand sizes and shapes, can be used as the basis for a product to assist those who lack hand strength. In future studies, we plan to measure pen tilt, sentence completion time, and upper extremity muscle activity using the NDWAD. Additionally, a study on the development of a writing posture correction device will be conducted using finger pressure and pen tilt data collected through Arduino.
Author Contributions: Conceptualization, S.K.; methodology, S.K., J.-Y.J. and C.-M.Y.; formal analysis, S.K.; investigation, S.K., J.-Y.J. and Y.-K.L.; writing—original draft preparation, S.K.; writing—review and editing, S.K. and J.-J.K.; project administration, J.-J.K.; funding acquisition, J.-J.K. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by a grant from the National Research Foundation of Korea (NRF) funded by the Korean government (MSIT) (No. NRF-2019R1A2C1008454).

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board of Jeonbuk National University (IRB File No. JBNU 2021-08-012).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data of this study are available on request from the corresponding author.

Acknowledgments: This paper was proofread by the Writing Center at Jeonbuk National University in November 2021.

Conflicts of Interest: The authors declare no conflict of interest.

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