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Adjusting touchscreen operation for individuals with cerebral palsy

Ting-Fang Wu
Professor,
Graduate Institute of Rehabilitation Counseling,
National Taiwan Normal University

Abstract

Rationale and Purpose: Touchscreens are increasingly prevalent in daily life. Touchscreen controls are considered more intuitive and easier to use for users than are traditional interfaces. However, operating touchscreens requires dexterous finger movements that may represent a limitation for people with physical disabilities, such as cerebral palsy (CP). CP is a group of permanent movement, posture, and motor function disorders that arise due to non-progressive abnormality of the developing/immature brain. Because of abnormal muscle tone, people with CP have difficulties controlling their movements, especially fine movements. Although iOS and Android operating systems have built-in adjustable settings to meet a wide range of users' needs, including voice, head, eye, and gesture controls, these may not necessarily fully remedy the situation for those with CP. Hence, tailoring the adjustable settings and user interfaces of touchscreen devices for individuals with CP is a critical goal of rehabilitation and special education professionals. The present study determined the optimal adjustment strategies for an occupational therapist assisting three individuals with CP in using smartphones. **Methods:** The present study used a single-subject research design and alternative treatment method to quickly compare intervention methods and determine the most suitable adjustment strategy for each patient. Three participants—Amy, Helen, and Jane—were recruited from a special education school in northern Taiwan. They were all 18 years old, female, and their parents or guardians provided informed consent for their participation. A researcher-designed app named the Accessibility Assessment System (AAS) was used to collect data. We conducted a tapping test to collect data on participants' performance because tapping is used most frequently when interacting with touchscreens. In the tapping test, the sizes of icons and the areas accessible to the participant were assessed through continual tapping tasks. Four modules (5 × 4, 4 × 3, 3 × 2, and 2 × 1) were designed on the basis of icon size. The present study was conducted during one-on-one sessions between participants and a school occupational therapist. In the baseline phase (A), data were collected concerning the participant's typical posture and placement when using a smartphone. During alternating treatment phase 1 (B1), the researchers increased the icon size or extended the reaction time to determine the most suitable operational mode for each participant. The three adjustment strategies were as follows: 5 × 4, 2 s; 4 × 3, 1 s; and 4 × 3, 2 s. During alternating treatment phase 2 (B2), two operating postures were compared: one was the original operating position of the participants, and the other involved fixing the smartphone at eye height with a support-placing frame. During the maintenance phase (C), we continued to collect data to determine whether the strategy had sustained effects. **Results:** Our results indicated that all three participants progressed through the adjustment process. During the baseline phase, the tapping accuracy rate of Amy ranged from 5% to 20% with an average of 10.8%. During the B1 intervention phase, Amy's accuracy rate increased from 10.8% to 86.5% with longer reaction times (5 × 4, 2 s), to 22.5% with larger icon sizes (4 × 3, 1 s), and to 98.3% with a combined strategy (4 × 3, 2 s). During phase B2, Amy's average accuracy rate for tapping on the touchscreen was 94.4% without a support-placing frame and 95.8% with a support-placing frame to adjust the height of the smartphone. During the maintenance phase, Amy's performance continued to improve and eventually reached an accuracy rate of 100%. The tapping accuracy rate of Jane ranged from 0% to 5% with an average of 4% during the baseline phase. When enlarging the icon size (4 × 3, 1 s), extending the response time (5 × 4, 2 s), and combining these two strategies (4 × 3, 2 s), Jane's correct rate increased from 4% to 34.2%, 74.5%, and 90.8%, respectively. The accuracy rates of tapping for Jane in the B2 phase ranged from 75% to 91.6% (with an average of 80.5%) without an added support-placing frame and 91.6% to 100% (with an average of 94.4%) with an added support-placing frame. During the maintenance phase, Jane's performance continued to improve and eventually reached an accuracy rate of 100%. The tapping accuracy rate of Helen ranged from 5% to 40% with an average of 26.9% during the baseline phase. When enlarging the icon size (4 × 3, 1 s), extending the response time (5 × 4, 2 s), and combining these two strategies (4 × 3, 2 s), Helen's correct rate increased from 26.9% to 52.3%, 86%, and 94.1%, respectively. The accuracy rates of tapping for Helen in the B2 phase ranged from 83.3% to 100% (with an average of 93.3%) without a support-placing frame and 91.6% to 100% (with an average of 98.3%) with a support-placing frame. During the maintenance phase, Helen's performance continued to improve and eventually reached an accuracy rate ranging from 91.6% to 100% with an average of 95%. During the B1 intervention phase, among the three strategies, the best adjustment strategy for increasing the tapping accuracy rate of all three participants was to combine longer reaction times with larger icon sizes. Adding a support-placing frame was helpful for some of the participants with CP. In this study, Jane improved her accuracy rate after the support-placing frame was added, but Amy and Helen did not. However, raising the smartphone to eye level with a support-placing frame could improve the participants' posture during operation as well as reduce the neck and shoulder pain caused by looking down at the smartphone on the lap tray. All three participants appreciated this adjustment. **Conclusions and Implications:** The evidence in this study demonstrated the effectiveness of implementing various strategies to assist individuals with CP in using touchscreen mobile devices and further demonstrated that extending reaction time, increasing target size, and providing additional support are effective strategies for helping individuals with CP to operate smartphones; moreover, the strategies were effective irrespective of differences in muscle tone or motor control. The various adjustments implemented in this study can serve as a reference for those assisting patients with CP in clinical practice. However, this study only evaluated the difficulties of and possible adjustments for tapping on smartphones for individuals with CP. Future studies should explore other difficulties and adjustments for CP in operating smartphones. How to overcome physical disabilities other than CP should also be investigated through the same procedure to determine best practices.

Keywords: adjustment strategies, cerebral palsy, single-subject research design, tapping, touchscreen,

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* Corresponding Author: tfwu@ntnu.edu.tw

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1. Introduction

According to the 2020 Taiwan Internet Report conducted by the Taiwan Network Information Center, in the recent 6 months, 83.0% of Taiwanese aged greater than 12 years had accessed the internet, and 82.9% of them had used smartphones to do so (Taiwan Network Information Center, 2020). Most smartphones offer touchscreen interaction, which is not only relatively effortless but also intuitive to perform. Touchscreens are becoming increasingly prevalent in daily life for reading, shopping, banking, making calls, and working (Duff et al., 2010). Compared with traditional interfaces, touchscreens provide a more effective and efficient way of teaching and learning (Manuguerra & Petocz, 2011). Special education and rehabilitation professions also began to use touchscreens in daily life, school work, employment, communication, self-prompt, and leisure applications for persons with disabilities (Stephenson & Limbrick, 2015). However, using a touchscreen requires dexterous finger movements, which may be particularly problematic for people with physical disabilities (Anthony et al., 2013; Duff et al., 2010). The User Needs Survey conducted between 2012 and 2013 by the Rehabilitation Engineering Research Center for Wireless Technologies found that about 40% of people with physical disabilities have feature phones instead of smartphones (Morris et al., 2014). This might be due to basic mobile phones with physical buttons are less likely to be accidentally touched by fingers and can provide tactile feedback. For persons with physical disabilities, operating smartphones with a touchscreen may still have many obstacles (Morris et al., 2014).

Cerebral palsy (CP) is one of the diseases that may cause physical disabilities. It is a group of permanent, but not unchanging, disorders of movement and/or posture and of motor function, which are due to a non-progressive interference, lesion, or abnormality of the developing/immature brain (Sadowska et al., 2020). Due to the influence of abnormal muscle tone, it is particularly difficult for people with CP to control their movements, especially fine movements (Davies et al., 2010). Among individuals with CP, 85% may possess spastic muscle tone, which may interfere with their ability to perform the dexterous finger movements required to operate touchscreens (Horstmann & Beck, 2007).

Despite the widespread use of touchscreens, research on the accessibility to people with physical disabilities remains scarce. Mott et al. (2018) employed questionnaires to interview people with physical disabilities regarding their experience of using smartphones and found that 69.4% of participants had difficulties in stabilizing their phones. Although literature suggested that people with physical disabilities can operate touchscreens with eye gaze, they also pointed out the difficulties of eye gazing, including those screens usually do not have a set angle to the eyes (Drewes et al., 2007). Both iOS and Android operating systems have built-in adjustments, including voice control, head control, eye control, or gestures instead of tapping to meet various users' needs (Apple, 2021). However, individuals with CP have difficulties in voluntary motor control even with those built-in adjustments. The efficiency of controlling voice, head, eye, or gesture is not good enough and still requires assistance, such as support-placing frame the mobile phone with a stabilizer. In addition, CP is a heterogeneous disorder, thus the movement patterns of individuals might vary greatly. Therefore, built-in adjustments might not meet each individual's needs. Tailoring adjustments and user interfaces in touchscreen devices for individuals with CP is a critical goal of rehabilitation and special education professionals. The present study aimed to determine the optimal adjustment strategies for an occupational therapist in assisting 3 individuals with CP to use smartphones.

2. Literature review

2.1. Operation gestures of touchscreen mobile devices

Touchscreens have become mainstream in the market due to their effortless and intuitive operation (National Development Council, 2019). The basic operation gestures include tapping, double-tapping, flicking (sliding), dragging, pinching (zooming in and out), long-pressing, and rotating (Villamor et al., 2010). The complexity of operation gestures a child is capable of performing on touch interfaces increases with age. Two-year-old toddlers can successfully tap and slide, and 3-year-old preschoolers can successfully tap, slide, drag, and rotate. By 4 to 5 years of age, children can perform all gestures except for double-tapping, since they are not capable of acting at the required tapping speed (Samarakoon et al., 2019). Of all the touchscreen gestures, tapping is the easiest and most frequently used (Aziz et al., 2014). Therefore, this article will focus on the adjustment of tapping for persons with CP.

2.2. Difficulties faced by people with physical disabilities in operating touchscreen mobile devices

Compared with physical buttons, touchscreens save effort, which might be beneficial for people with motor impairments due to their poor muscle strength; however, it might also cause varying degrees of difficulty due to their limited dexterity (Trewin et al., 2013). Researchers observing the touchscreen operation of 187 people with motor impairments through video found that 91% of users used direct selection, for which the index finger or the combination of thumb and index finger was the most frequently used, but a few users also used other body parts such as their nose and feet. Only 8% of people with motor impairments used an indirect selection method such as a head pointer (Anthony et al., 2013).

People with physical disabilities are unable to fully extend their fingers because of their higher muscle tone or to touch the touchscreen with their fingernails, meaning that their input cannot be recognized (Anthony et al., 2013). Moreover, they might press the screen for too long, resulting in a longer dwell time. They also might not be able to access all areas of the screen due to the restricted range of motion in the upper extremities (Anthony et al., 2013). Tapping is the simplest and most frequently used gesture for interacting with a touchscreen. The error rates of pinching and sliding are usually higher than those of tapping (Trewin et al., 2013).

To understand difficulties in people with upper-extremity impairments while using touchscreens, Findlater et al. (2017) compared the operation performance of 16 participants with motor impairments to those without such impairments. The results indicated that touchscreen input was faster than mouse input only for participants without motor impairments. The touchscreen error rate for participants without motor impairments was 3.2%, but eight times higher (25.1%) for those with impairments (Findlater et al., 2017).

Participants with motor impairments had a three-fold higher error rate for tapping compared with mouse input. For this population, the size of the target had a significant impact on their tapping error rate. The error rate of participants with motor impairments was 42.1% at 6 mm^2, but the error rate decreased considerably to 7.0% when the target size was increased to 18 mm^2. However, the impact of target size on the tapping error rate was nonsignificant for those without motor impairments. Their error rate at 18 mm^2 was almost 0%. Even at the smallest size of 6 mm^2, their error rate was only 7.4%. (Duff et al., 2010; Irwin & Sesto, 2012). Trewin et al. (2013) conducted a study that set up a screen with three 12-mm purple circles and asked people with and without physical disabilities to tap the targets on the screen. Compared with people without disabilities, the rate of missing targets for people with physical disabilities reached 23%, whereas it was 0% for people without disabilities. People with physical disabilities pointed out their difficulties with operating touchscreen devices, such as pressing an unwanted target or failing to press it for more than 5 seconds (Trewin et al., 2013). Other studies also showed that people with motor impairments have lower accuracy rates, slower speeds, and longer dwell times when tapping (Duff et al., 2010; Irwin & Sesto, 2012).

Individuals with CP have difficulty in performing individual finger movements due to hypertonic muscle tone; therefore, they cannot easily perform smooth sliding or dragging actions on a touchscreen. In addition to tapping, the most difficult gestures for people with physical disabilities are multitouch gestures, text input, and correction. Other difficulties include zooming in and out, pressing switches, and providing voice input (Naftai & Findlater, 2014).

2.3. Adjustment strategies for mobile devices

2.3.1. Providing control enhancers

In the study by Anthony et al. (2013), 13% of participants with physical disabilities used arm or leg slings for stabilization to enhance the control over their extremities to touch the screen. Some people mounted the mobile device on the wheelchair with a mounting system or on a table/lap tray with Velcro (Valencia et al., 2017).

When a mobile device is placed on the table, the head and neck can be bent more than required when the device is upright, which may cause more biomechanical stress on the neck and shoulders. However, if the mobile device is placed 60-70° from the horizon, fingers, wrist, and shoulder are in unnatural positions when tapping the touchscreen. Therefore, mounting devices around 33-37° from the horizon allows a posture with the least biomechanical stress on the neck and shoulders (Toh et al., 2017).

2.3.2. Providing alternative input methods

Anthony et al. (2013) analyzed 187 videos of physically disabled people manipulating a touchscreen and found that 15 of them used indirect interaction to touch the screen due to poor finger dexterity. Among these 15 people, 4 of them used head sticks, 7 used mouth sticks, and 4 used styluses. Some participants mentioned that head sticks were difficult to use because they could not tap quickly. In the study by Anthony et al. (2013), to reduce accidental touches, the areas that did not need to be touched were wrapped with foam. Some apps, such as Assistive Touch in Android systems, simplify complex gestures, allowing individuals with physical disabilities to replace complex gestures with simple ones.

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2.3.3. Increasing target sizes

Tapping accuracy is related to the size of the object being tapped. The suitable sizes for tapping and flicking are >14 mm^2 and >17.5 mm^2, respectively (Leitao & Silva, 2012). Findlater et al. (2017) suggested that the target size for tapping by individuals with motor impairments should be at least 18 mm^2. Guerreiro et al. (2010) compared the performance of individuals with spinal cord injury on three tap heatmap sizes (7, 12, and 17 mm^2) and found significant differences in their performance on the 7 mm2 heatmap compared with the 12 mm2 and 17 mm2 ones. The researchers inferred that 12 mm^2 is the most suitable size for people with movement disorders (Guerreiro et al., 2010). Duff et al. (2010) compared the performance of participants with or without movement impairments when operating buttons of five sizes. The findings indicated that the smaller the button, the higher the error rate was. Duff et al. suggested that smaller buttons would significantly reduce operation performance and the button size should be at least 20 mm^2.

Sesto et al. (2012) studied the differences in force characteristics, impulses, and dwell times of different icon sizes for adults with movement disorders. The results indicated that when the icon sizes were enlarged, the user exerted more force. When the icon sizes increased from 10 to 30 mm^2, the user increased the force by 17%. The sizes of the icons also affected the dwell times of the users. The results indicated that when the icon sizes were enlarged and the dwell time decreased. When the icon size increased from 10 to 30 mm^2, the staying time of the user was reduced by 27%. Types of movement disorders also affected the time staying on the icons. People with CP or Huntington's disease stayed on the icons 1.6 times longer than those with multiple sclerosis or Parkinson's disease, and 2.3 times longer than normal people.

2.3.4. Providing indirect selection methods

If the aforementioned adjustment methods do not help an individual with physical disabilities to perform tapping on a touchscreen, an indirect selection method such as adding an external Bluetooth keyboard or mouse should be considered. For those who cannot tap on a touchscreen, an external joystick, mouse, trackball, or switch combined with a scanning method can be used. The scanning method and scan duration are adjusted according to the needs of the individual (Apple, 2021; Pérez, 2013). Switch control is currently built into iOS, whereas for Android system users, free apps such as Air Switch, Tecla Access, and Switchboard: Assistive Disabled Switch Access must be downloaded.

Although the previous adjustment strategies for mobile devices have been recommended in the literature, there was no suggestion for the priority of selection of them. When adjusting computer keyboard and mouse inputs, direct selection methods were often prioritized over indirect selection ones (Anson, 1994, 1997; Wu et al., 2014). This principle was also applied to adjusting mobile devices for people with physical disabilities. As direct selection methods, increasing target sizes and providing control enhancers were often recommended by literature. In addition, some commercially available software inputs had reaction time requirements. Thus, the present study also considered the adjustment of reaction time as one of the adjustment strategies.

At present, few relevant research results have been published, and more case studies are required to prove the effects of adjustment strategies on the ease of mobile device use for individuals with CP. Therefore, the present study aimed to explore the difficulties faced by 3 individuals with CP when using smartphones and to recommend appropriate strategies for adjusting the touch interface.

3. Method

3.1. Participants

The research participants of this study are purposed sampling. The recruiting criteria were: (1) being diagnosed with CP, (2) having difficulty in operating the touchscreen interface due to poor motor control, (3) being able to remain upright for more than 30 minutes with support, and (4) being able to follow instructions. Three participants - Amy, Helen, and Jane - were recruited from a special education school in Northern Taiwan. They were all 18 years old, female, and informed consent to participate in this study was obtained from their parents or guardians.

Amy has left hemiplegia with her left limbs affected by spasticity. Her Manual Ability Classification System (MACS) level is II, indicating that she can handle most objects but with some reduced quality and/or speed. MACS is a 5-level classification system that describes how children with CP (from age 4 to 18) use their hands to handle objects in daily activities, while level I is the least severe and level V is the most severe (Eliasson et al., 2006). Amy usually placed her smartphone on the lap tray of the wheelchair and used her right index finger to operate and her left hand to stabilize the phone. She stated that she uses her smartphone to make phone calls, use Line and Facebook, play games, and watch videos. When opening an app, she stated that she often taps the wrong icon due to her uneven finger movements.

Jane has tetraplegia, which means that all her limbs are affected by spasticity. Her MACS level is IV, indicating that she can only handle a limited selection of easily managed objects and always requires some help from others (Eliasson et al., 2006). Jane also placed her smartphone on the lap tray and used her left middle finger with cock-up splint to operate it. She mainly used her smartphone to play games by tapping the screen with her left middle finger, but her excessive muscle tone often pushes the smartphone too much and causes displacement.

Helen has diplegia with all her limbs affected by spasticity but upper limbs less affected. Her MACS level is II, indicating that she can handle most objects but with some reduced quality and/or speed (Eliasson et al., 2006). Helen used her right index finger to operate the phone. She also stated that she uses her smartphone for several apps, including Facebook, Line, and games. She also complained of difficulties in holding the phone and tapping the right app icons.

All three participants usually played simple puzzle games, such as Candy Crush and Fruit Ninja, which involved tapping and sliding on the touchscreen. They also complained about shoulder and neck pain due to their poor posture when operating smartphones.

3.2. Instrument

A self-designed app called Accessibility Assessment System (AAS) was used in this study to collect the data. AAS was designed to be a cloud-based app accessed through the web for helping the research team build, test, maintain, update, and scale accessibility assessments for smartphones (Wu et al., 2020). The web server architecture combines the Apache web server with PHP, Perl, and MariaDB, allowing users to easily connect to the web server with their smartphones. The design of AAS is task-oriented, including tapping, sliding, and dragging, which adopts a game-style scenario to induce the participant's motivation. In addition, the results of assessments were automatically uploaded to a cloud database for further analysis.

In this study, we used a tapping test to collect data on participants' performance since tap has been used most frequently when interacting with touchscreen (Trewin et al., 2013). Tap was defined as pointing and selecting the icon on the touchscreen of a smartphone. In the tapping test, the sizes of icons and the areas that the participant was able to access were assessed through continual tapping tasks. Four modules (5×4, 4×3, 3×2, and 2×1, Figure 1a–d) were designed according to the different sizes of the icons. For example, Module 5×4 means that the icons on the touchscreen were arranged in five rows and four columns, and the size of each icon was 17×18 mm^2 (Figure 1a). The icon size of the 4×3 module was 22×27 mm^2 (Figure 1b).

The icons were randomly displayed on the touchscreen, and the display time of each icon can be set from 1 second to 99 seconds. Participants were asked to tap the icons within the set time and the time to complete the tapping tasks was recorded along with the accuracy and area of correct taps (Figure 1e-h). For instance, Figure 1e indicates the correct tapping area of the 5×4 module. In addition, a Redmi Note 8 smartphone, which is 6.23×2.96 in^2, was used to collect data.

3.3. Experimental design

Due to the heterogeneous characteristics of CP, a method that is suitable for one individual with CP may not be suitable for others; therefore,

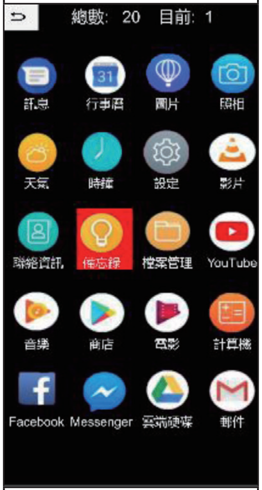


Fig. 1a: touchscreen layout of the 5×4 module.


Fig. 1b: touchscreen layout of the 4×3 module.


Fig. 1c: touchscreen layout of the 3×2 module.


Fig. 1d: touchscreen layout of the 2×1 module.

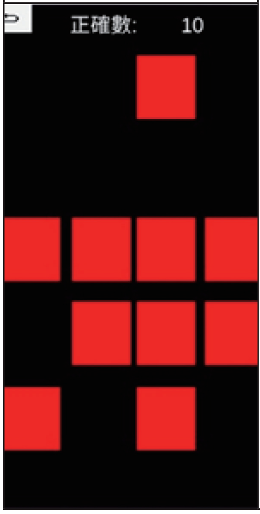


Fig. 1e: correct tapping area of the 5×4 module.

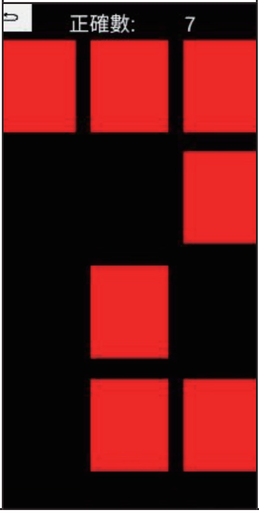


Fig. 1f: correct tapping area of the 4×3 module.

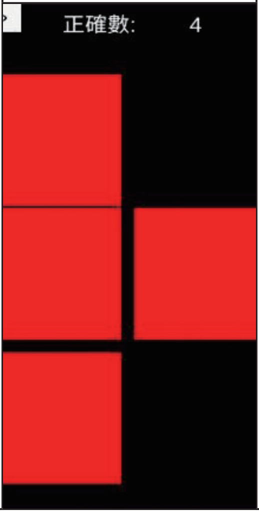


Fig. 1g: correct tapping area of the 3×2 module.

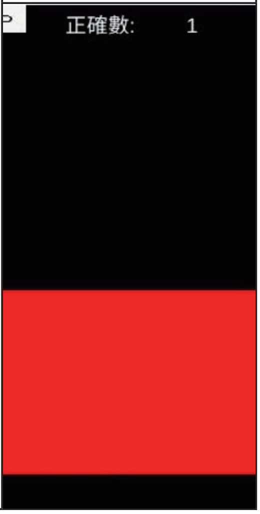


Fig. 1h: correct tapping area of the 2×1 module.

this study adopted the single-subject research method to identify the most suitable adjustment strategy for each participant. In addition, because several adjustment strategies could be applied to the participants, alternating treatment design (ATD) was employed, which can be used quickly to alternate and compare two (or more) adjustment strategies and finally select the better (or best) strategy of the two (or more) (Alberto & Troutman, 2003; Tawney & Gast, 1984). We used ATD to compare several operating interfaces and delay times to select the most suitable operating environment for each participant.

The independent variables were icon sizes and the time of each icon presented on the touchscreen. The icon size ranged from 17×18 mm^2 (module 5×4) to 69×53 mm^2 (module 2×1). The time of each icon presented on the touchscreen can be set from 1 second to 99 seconds. The dependent variable was the correct rate of tapping on the touchscreen defined by the number of icons correctly taped over the number of icons shown on the touchscreen. Error types included not pressing the target, pressing the wrong one, and not pressing the target within the set time.

3.4. Procedure

The present study was conducted in one-on-one sessions by a school occupational therapist. Data were collected once a day, and usually 5 days a week unless the participants took sick leave. The occupational therapist usually moved the participants from their classroom to a quiet room. ATD was used to compare the effects of the different adjustment strategies for individuals with CP using smartphones.

Setup phase: Before collecting data, the interface and response time of the smartphone were set based on a previous test we conducted with six typically developing teenagers from age 12 to 18. These six teenagers were assessed using the 5×4 module on the touchscreen, and the response time was set at 1-second intervals. The mean average accuracy rate for tapping (5×4, 1s) was 95%; therefore, the 5×4, 1s module was used to collect the baseline data.

Baseline phase (A): In the baseline phase, data were collected based on the participant's typical posture and placement when using a smartphone. When the baseline period data were stable, then the study entered alternate intervention phase 1.

Alternating treatment phase 1 (B1): In this phase, the researchers adjusted the icon size to be larger or extended the reaction time to determine the most suitable operation mode for each participant. The three adjustment strategies were as follows: 5×4, 2s; 4×3, 1s; and 4×3, 2s. Finally, the most efficient operating mode among the three was determined.

Alternating treatment phase 2 (B2): After the operation interface mode was determined, the goal of the subsequent phase was to determine a more favorable operating posture. Two operating postures were compared: one was the original operating position of the participants, and the other involved adding a support-placing frame to place the smartphone at eye height and maintaining a 40° angle with the lap tray.

Maintenance phase (C): By using the optimal adjustment strategy, we continued to collect data to further understand whether the strategy had sustained effects. Finally, interviews were conducted to understand how the participants felt about the adjustment strategies.

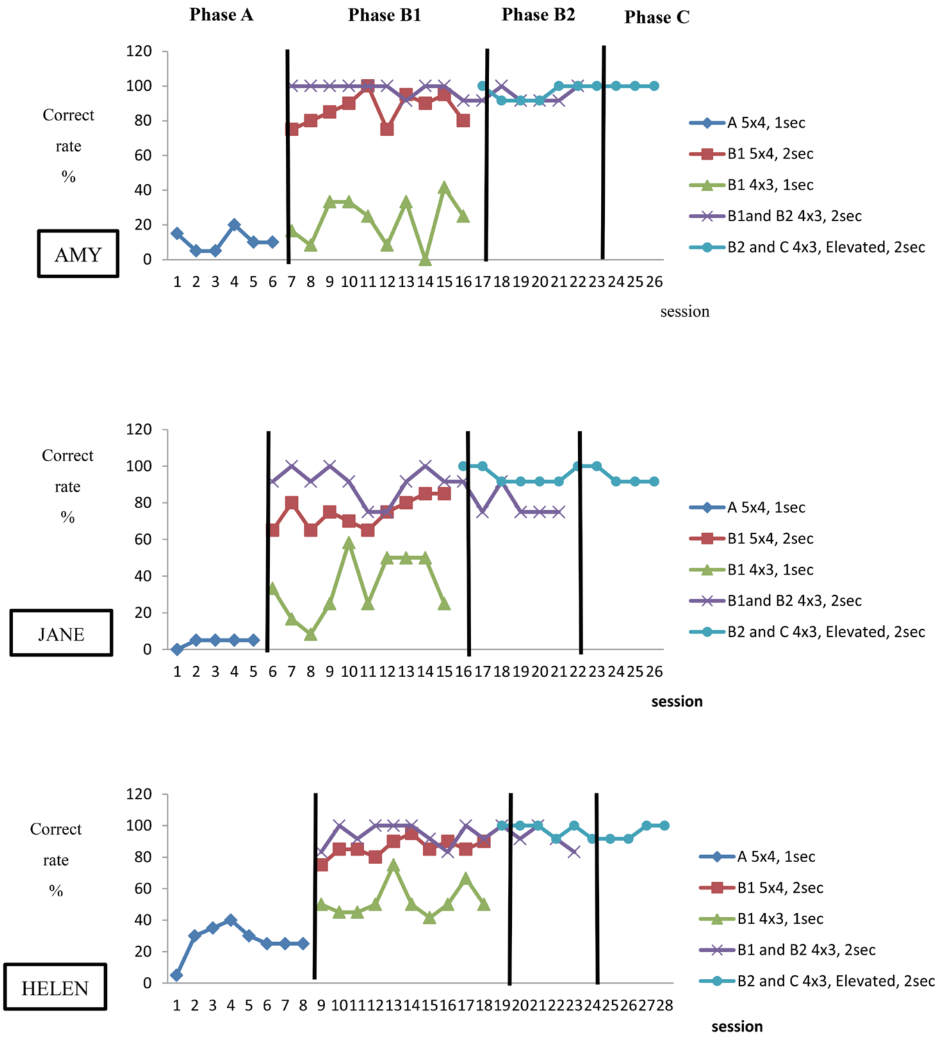
4. Analysis and results

The graph in Figure 2 presents the participants' performance on tapping the touchscreen in phases A, B1, B2, and C.

4.1. Amy

The accuracy rate of tapping on the touchscreen for Amy was illustrated in Figure 2 and visual analysis was demonstrated in Appendix 1.1. During the baseline phase, the tapping accuracy rate of Amy was ranging from

Figure 2. The accuracy rate of tapping on the touchscreen among the three participants



5% to 20% with an average of 10.8%.

During the B1 intervention phase, three adjustment strategies - extending the reaction time (5×4, 2s), enlarging the icon sizes (4×3, 1s), and combining longer reaction times with larger icon sizes (4×3, 2s) were implemented. Amy's accuracy rate increased from 10.8% to 86.5% with longer reaction times (5×4, 2s), to 22.5% with larger icon sizes (4×3, 1s), and to 98.3% with combined strategy (4×3, 2s). Comparing different strategies within the B1 phase, the overlapping rate of the combined strategy (4×3, 2s) and; therefore, this was selected as one of the strategies in the next phase.

During phase B2, we alternated two different adjustment strategies: one was the optimal strategy from phase B1 and the other involved adding a support-placing frame to place the smartphone at eye height and maintain it at 40% of the horizontal plane. Amy's average accuracy rate for tapping on the touchscreen was 94.4% when the icon size was enlarged and the reaction time was extended. The average accuracy rate was 95.8%, with a support-placing frame added to adjust the height of the smartphone. When comparing these 2 strategies with B2, the change in level is 0 and the overlapping rate is 100% which indicates there was no significant difference in the accuracy of Amy's accuracy rate with and without the support-placing frame of the smartphone. However, Amy's posture was more upright and the angle of neck flexion was reduced when providing the support-placing frame to mount the smartphone. Therefore, the strategy with a support-placing frame for the smartphone was selected as the one in the maintenance phase.

During the maintenance phase, Amy's performance continued to improve and finally reached an accuracy rate of 100%. The level and trend stability were both 100%. And compared with B2 (4×3, 2s, elevated), the average level change is 0, and the overlap rate is 100%, showing Amy maintained a satisfactory accuracy rate.

4.2. Jane

As Shown in Figure 2 and Appendix 1.2, the tapping accuracy rate of Jane was ranging from 0 to 5% with an average of 4% during the baseline phase. When enlarging the icon size (4×3, 1s), extending the response time (5×4, 2s), and combining these two strategies (4×3, 2s), Jane's correct rate increased from 4% to 34.2%, 74.5%, and 90.8%, respectively.

When comparing B1 (5×4, 2s) and baseline phases (B1 5×4, 2s /A1), the change in level was positive, with a level change of +60%, indicating the time extending helps Jane's accuracy. When comparing B1 (4×3, 1s) and baseline phases (B1 4×3, 1s /A1), the change in level was positive, with an overlapping rate with the baseline is 0%, indicating icon enlargement helps Jane's accuracy rate increase. When comparing B1 (4×3, 2s) and baseline phases, a level change of +86.6% with an overlapping rate is 0%, indicating the effect of combining icon size enlargement and longer response time at the same time is the most significant.

During phase B2, we alternated two different adjustment strategies: one was the optimal strategy from phase B1 and the other involved adding a support frame to place the smartphone at eye height. The accuracy rates of tapping for Jane in the B2 phase were ranging from 75% to 91.6% (with an average of 80.5%) without a support-placing frame and 91.6% to 100% (with an average of 94.4%) with a support-placing frame. When comparing these 2 strategies with B2, the change in level is +25 and the overlapping rate is 33% which indicates that elevating the height of the smartphone is indeed effective for improving the accuracy of Jane's operation. Therefore, the strategy with a support-placing frame for the smartphone was selected as the one in the maintenance phase.

During the maintenance phase, Jane's performance continued to improve and finally reached an accuracy rate of 100%. The level and trend stability were 0% and 40%, respectively. Compared with B2 (4×3, 2s, elevated), the average level change is -8.4, and the overlap rate is 100%. Helen's performance declined slightly during the first four sessions; however, it had reached 100% by the end of the maintenance phase.

4.3. Helen

As shown in Figure 2 and Appendix 1.3, the tapping accuracy rate of Helen was ranging from 5% to 40% with an average of 26.9 % during the baseline phase. When enlarging the icon size (4×3, 1s), extending the response time (5×4, 2s), and combining these two strategies (4×3, 2s), Jane's correct rate increased from 26.9% to 52.3%, 86%, and 94.1%, respectively.

When comparing B1 (5×4, 2s) and baseline phases (B1 5×4, 2s /A1), the change in level was positive, with a level change of +59.1%, indicating the time extending helps Helen's accuracy rate. When comparing B1 (4 × 3, 1s) and baseline phases (B1 4×3, 1s /A1), the change in level was positive, with an overlapping rate with the baseline is 0%, indicating icon enlargement helps Helen's accuracy rate increase. When comparing B1 (4×3, 2s) and baseline phases, a level change of +67.2% with an overlapping rate with the baseline is 0%, indicating that increasing the icon size and extending the response time at the same time, the effect of improving the accuracy of tapping is the most significant.

During phase B2, we alternated two different adjustment strategies: one was the optimal strategy from phase B1 and the other involved adding a support frame to place the smartphone at eye height. The accuracy rates of tapping for Helen in the B2 phase were ranging from 83.3% to 100% (with an average of 93.3%) without a support-placing frame and 91.6% to100% (with an average of 98.3%) with a support-placing frame. When comparing these 2 strategies with B2, the change in level is 16.7%, but the overlapping rate is 33% which indicates that elevating the height of the smartphone has only a slight effect on the accuracy of Helen's operation. However, Helen's posture was more upright and the angle of neck flexion was reduced when providing the support-placing frame to mount the smartphone. Therefore, the strategy with a support-placing frame of the smartphone was selected as the one in the maintenance phase. During the maintenance phase, Helen's performance continued to improve and finally reached an accuracy rate ranging from 91.6% to 100% with an average of 95.0%, indicating Helen maintained a satisfactory accuracy rate.

4.4 Summary

Three participants were not proficient in tapping since all accuracy rates remained low during the baseline phase. During the B1 intervention phase, three different strategies were implemented. Among the three strategies, the best adjustment strategy to increase the tapping accuracy rate for all three participants was combining longer reaction times with larger icon sizes (4×3, 2s). During phase B2, we alternated two different adjustment strategies: one was the optimal strategy from phase B1 and the other involved adding a support frame to place the smartphone. Adding a placing support frame was helpful for some of the persons with CP. In this study, we found Jane improve her accuracy rate after adding the placing support frame, but Amy and Helen didn't. However, raising the smartphone to eye level with a support frame can improve the participant's posture during operation as well as reduce neck and shoulder pain caused by looking down at the smartphone on the lap tray. All three participants appreciated this adjustment. During the maintenance phase, all three participants reached an accuracy rate of 100% and maintained a high accuracy rate.

5. Discussion and conclusion

The present study used a single-subject research design and alternative treatment method to quickly compare intervention methods for determining the most suitable adjustment strategy specific to an individual. CP is a heterogeneous disorder. Movement restrictions and adjustment strategies while using mobile devices are different among individuals with CP. Therefore, the single-subject research method is suitable for this type of individualized adjustment research.

This study presented the adjustment process for three individuals with CP using smartphones. To efficiently compare different strategies, both the icon size and the response time of the touchscreen were adjusted during alternating treatment phase B1. Figure 2 showed that the adjustment of the response time was more effective than the adjustment of the icon size for all three participants. Previous literature had indicated that it took more time for children with CP in reaching movements than typically developing peers, even with their less affected limbs (van der Heide et al., 2005). Therefore, prolonging the reaction time would meet the needs of individuals with CP.

Figure 2 revealed that the effect of prolonging the reaction time for Jane was not as good as that of the other two participants. This is probably because Jane was most affected by spasticity among the three participants. Previous literature had indicated that the quality of reaching for persons with CP was affected by the severity of brain lesion, motor disorder, and spasticity (van der Heide et al., 2005).

Besides extending the response time, enlarging the size of the icons was also suggested in the literature. Guerreiro et al. (2010) recommended that a 12 mm^2 icon size would be the most suitable for people with movement disorders. Other studies (e.g., Duff et al., 2010) also suggested increasing the icon size to 20 mm^2. According to our results, when the icon was increased to 22×27 mm^2, the accuracy rate of tapping of the three participants could be close to 100%. In this study, Jane benefited most from the increment of icon size. Jane's MACS Level is IV, which is the worst hand ability among the three participants and her movement accuracy was also the lowest. Adjusting the size of the target provided her with the most obvious feedback. The strategy of enlarging the target is also highly suitable for the elderly and children, but the target cannot be excessively enlarged because it would affect the information presented on the screen. Therefore, when a target is magnified, the actual needs of individuals must be considered and other adjustment strategies must be combined.

According to the literature, the icon size also significantly affected dwell times for people completing a number entry task on a touchscreen. People with physical disabilities had longer dwell times than people without disabilities (Sesto et al., 2012). Our results also indicated that when the target size was maintained the same, the accuracy could be higher when the input speed was reduced. When the speed remained the same, the accuracy would be higher when the target size increased.

In the second phase of alternate treatment, the optimal strategies from the previous phase were compared with another adjustment which was adding a mounting system for supporting the smartphone in a more comfortable position. In the alternate treatment phase B2, in addition to increasing the icon size and slowing the response time, providing a mounting system at an angle of 40° horizontally to fix the smartphone and elevated the smartphone was used. The results showed that the average level of Jane was higher than when they were not fixed. Jane has tetraplegia, which affected all her extremities with her upper limbs being more severe than her lower limbs. Thus, her ability to maintain head stability was the worst among the three participants. To reduce the requirement of head control, providing an external frame to support the mobile phone at the appropriate position might bring the most benefits for Jane. Even though providing a smartphone mounting system might not increase the accuracy for Amy and Helen effectively, external mounting systems would still assist them in maintaining good operating postures. For some individuals with physical disabilities, the fatigue or pain caused by prolonged mobile device use will affect their operation performance (Kane et al., 2009). Elevating the location of a smartphone could facilitate the appropriate posture for an individual while operating the smartphone.

In the maintenance phase, all three participants maintained high performance, with only a slight decrease for Helen. We fixed the smartphone at an angle of 40° horizontally, which was close to that was used in the study by Toh et al. (2017). This angle of the mounting system can reduce bending of the head and neck without causing excessive extension of wrist joints. In the follow-up interviews, all three participants expressed satisfaction with this adjustment. In addition to their performance improvement, all participants consistently expressed that their head and neck pain was reduced.

The adjustment process for individuals with CP using touchscreen mobile devices has not yet been established. The process of collecting evidence proposed in this study demonstrated effectiveness in selecting proper strategies for individuals with CP using touchscreen mobile devices. It is important to provide a scientific clinical approach, which could collect the internal evidence, to determine an appropriate strategy for individuals with CP. The present study demonstrated that extending reaction time, increasing target size, and providing additional support are effective strategies for individuals with CP operating smartphones even with differences in muscle tone and motor control ability among the participants. A comprehensive evaluation process and adjustment strategy should be established in future studies.

6. Limitations and future research

This study had several limitations. First, we employed a single-subject research design; therefore, the results cannot be generalized to all individuals with CP. Second, the size of the smartphone screen may affect the actual sizes of the icon displayed. Due to the experimental nature of this study, the same smartphone was used for data collection. The results of this study might not directly reflect in smartphones used by the 3 participants in their daily lives. This study only discusses the difficulties and adjustments of tapping for persons with CP. Future studies should explore other difficulties and adjustments for CP in operating smartphones. Physical disabilities other than CP should be investigated with the same procedure to identify whether the strategies are applicable.

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APPENDIX 1.1 Visual analysis of tapping accuracy for Amy

Within phase	A	B1			B2		C
		5X4,2s	4x3,1s	4x3,2s	4x3,2s	4x3,2s,E	
Condition length	6	10	10	10	6	6	4
Level range	5-20	75-100	0-41.6	91.6-100	91.6-100	91.6-100	100-100
Level change	-5	5	8.4	-8.4	8.4	0	0
Average	10.8	86.5	22.5	98.3	94.4	95.8	100
Level stability (%)	83.3%	30%	20%	80%	0%	0%	100%
Trend stability (%)	66.67%	50%	30%	80%	66.7%	66.7%	100%
Trend direction	/	/	—	—	—	/	—
Within phase		B1(4x3,2s)/ B1(5X4,2s)	B1(4x3,2s)/ B1(4x3,1s)		B2(4x3,2s, E)/ B2(4x3,2s)		
Change in level		+20 (100-80)	+75 (25-100)		0(100-100)		
Change in average		+11.8	75.8		1.4		
Change in trend stable		V to S	V to S		V to V		
Percentage of overlap		10%	0%		100%		
Between phase		B1(5x4,2s)/A	B1(4x3,1s)/A	B1(4x3,2s)/A	B2(4X3,2s,)/ B1(4x3, 2s)	B2(4X3,2s,E)/ B1(4x3, 2s)	C/ /B2(4X3,2s, E)
Change in level		+65 75-10	+6.6 16.6-10	+90 100-10	0 91.6-91.6	+8.4 100-91.6	0 100-100
Change in average		75.7	11.7	87.5	-3.9	-2.5	4.2
Trend direction		/ to /	/ to —	/ to —	—to —	—to /	/ to —
Change in trend stable		V to V	V to V	V to S	V to S	S to V	V to S
Percentage of overlap		0%	30%	0%	100%	100%	100%

APPENDIX 1.2 Visual analysis of tapping accuracy for Jane

Within phase	A	B1			B2		C
		5X4,2s	4x3,1s	4x3,2s	4x3,2s	4x3,2s,E	
Condition length	5	10	10	10	6	6	5
Level range	0-5	65-85	8.3-58.3	91.6-100	75-91.6	91.6-100	91.6-100
Level change	5	20	-8.3	0	-16.6	-8.4	-8.4
Average	4	74.5	34.2	90.8	80.5	94.	95.0
Level stability (%)	100%	30%	100%	50%	0%	0%	0%
Trend stability (%)	100%	80%	40%	50%	50%	66.6%	100%
Trend direction	—	/	/	—	\	\	\
Within phase		B1(4x3,2s)/ B1(5 x 4,2s)	B1(4x3,2s)/ B1(4x3,1s)		B2(4x3,2s, E)/ B2 (4x3,2s)		
Change in level		+6.6 (91.6-85)	+66.6 (91.6-25)		+25 (100-75)		
Change in average		16.3	56.6		13.9		
Change in trend stable		V to S	V to V		V to V		
Percentage of overlap		0%	0%		33.3%		
Between phase		B1(5x4,2s)/A	B1(4x3,1s)/A	B1(4x3,2s)/A	B2(4x3,2s,)/ B1(4x3, 2s)	B2(4x3,2s,E)/ B1(4x3, 2s)	C /B2(4x3,2s, E)
Change in level		+60 65-5	+28.3 33.3-5	+86.6 91.6-5	+8.4 100-91.6	+8.4 100-91.6	+8.4 100-91.6
Change in average		70.5	30.2	86.8	3.6	3.6	0.6
Trend direction		—to/	—to/	—to—	—to\	—to\	\to\
Change in trend stable		S to S	S to V	S to V	V to V	V to V	V to V
Percentage of overlap		0%	0%	0%	33.3%	100%	100%

APPENDIX 1.3 Visual analysis of tapping accuracy for Helen

Within phase	A	B1			B2		C
		5X4,2s	4x3,1s	4x3,2s	4x3,2s	4x3,2s,E	
Condition length	8	10	10	10	5	5	5
Level range	5-40	75-95	41.6-75	83.3-100	83.3-100	91.6-100	91.6-100
Level change	20	15	0	8.3	-16.7	0	8.4
Average	26.9	86	52.3	94.1	93.3	98.3	95.0
Level stability (%)	75%	70%	50%	30%	40%	80%	0%
Trend stability (%)	87.5%	60%	70%	50%	80%	80%	100%
Trend direction	\	/	—	\	\	—	/
Within phase		B1(4x3,2s)/ B1(5 x 4,2s)	B1(4x3,2s)/ B1(4x3,1s)		B2(4x3,2s, E)/ B2 (4x3,2s)		
Change in level		-6.7 (83.3-90)	33.3 (83.3-50)		+16.7 (100-83.3)		
Change in average		+8.1	+41.8		5		
Change in trend stable		V to V	V to V		S to S		
Percentage of overlap		10%	0%		100%		
Between phase		B1(5x4,2s)/A	B1(4x3,1s)/A	B1(4x3,2s)/A	B2(4x3,2s,)/ B1(4x3, 2s)	B2(4x3,2s,)/ B1(4x3,2s)	C /B2(4X3,2s, E)
Change in level		50	25	58.3	8.4	8.4	-8.4
Change in average		+59.1 86-26.9	+25.4 52.3-26.9	67.2 94.1-26.9	-0.8 93.3-94.1	+4.2 98.3-94.1	-3.3 95.0-98.3
Trend direction		\to/	\to—	\to\	\to\	\to—	—to/
Change in trend stable		S to V	S to V	S to V	V to S	V to S	S to V
Percentage of overlap		0%	0%	0%	100%	4100%	100%

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腦性麻痺使用觸控螢幕操作之調整歷程

吳亭芳
國立臺灣師範大學復健諮商研究所
教授

觸控螢幕在日常生活中變得越來越普及，然而，它的操作需要靈巧的精細動作，這對肢體障礙者，尤其是腦性麻痺相當困難。儘管 iOS 和 Android 系統都有針對不同需求的使用者內建調整系統，但仍無法滿足每位腦性麻痺的特定需求。因此，本研究主要為職能治療師協助 3 名腦性麻痺學生使用智慧型手機觸控螢幕操作的調整過程。本研究以單一受試研究法交替處理設計，比較對觸控螢幕操作的不同調整策略，為 3 名腦性麻痺學生選出最合適的操作策略。結果顯示，增加目標大小和降低反應速度可以提高參與者在手機觸控螢幕上輕按任務的正確率。此外，提供固定智慧型手機的輔具有助於腦性麻痺學生的輕按任務表現。本研究可提供專業人員未來在評估腦性麻痺患者使用手機，調整觸控螢幕操作時的參考。

關鍵詞：單一受試、腦性麻痺、輕按、調整策略、觸控螢幕

＊本文作者通訊方式（tfwu@ntnu.edu.tw）。