An Evaluation of App-Based and Paper-Based Number Lines for Teaching Number Comparison

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Abstract: Number comparison is a fundamental skill required for academic and functional mathematics (e.g., time, money, purchasing) for students with disabilities. The most commonly used method to teach number comparison is number lines. Although historically paper number lines are used, app-based number lines may offer greater flexibility. This study compared using paper-based and app-based number lines to teach number comparison skills to students with intellectual disability using a single-subject alternating treatments design. Three secondary students with intellectual disability participated in a classroom setting during baseline and intervention phases and a simulated grocery store setting during generalization phases. Both the adapted paper-based and app-based number lines were effective for students with intellectual disability. However, the app-based number line was slightly more effective in terms of accuracy and completion time during number comparison and price comparison tasks.

Arabic number comparison is an important skill for students with disabilities – used in academic mathematics, other subject areas (e.g., science – comparing temperature, and history – comparing event timelines), and daily living skills (i.e., grocery shopping; Holloway & Ansari, 2009; Storey & Miner, 2011). Number comparison involves comparing the magnitudes of number representations, which can be non-symbolic numeral representation (two dots vs. three dots) or symbolic numeral representation (e.g., one vs. three or 1 vs. 3). The ability to compare magnitudes of Arabic numerals is important because Arabic numerals are the most common numerical representation present in one’s daily life (Cohen, Kadosh, & Walsh, 2009).

In order to perform number comparison independently, an individual must master the following skills: recognizing numerals, recognizing the association between numeral representations and magnitudes, and establishing a systematic understanding of language associated with number comparison (e.g., smaller, bigger) and the sequence of numerals (Confer, 2005; Faulkner & Cain, 2009). Students who master number comparison typically demonstrate a concept called mental number lines (Anghileri, 2006; Mosley, 2001). Mental number lines are mental representations of Arabic numerals, which are organized horizontally and sequentially (Ansari, Holloway, Price, & Van Eimeren, 2008; Sousa, 2008).

There are many approaches to teaching number comparison. Among these approaches, number lines – which provide visual cues of numerical ordering relationships – are the most common method used from pre-K to grade 8 (Confer, 2005). Typically developing students acquire a mental number line at approximately 8 years of age (Okamoto, 2010). For students with disabilities, and specifically students with an intellectual disability, number comparison remains a challenge (Sandknop, Schuster, Wolery, & Cross, 1992). The difficulty with number comparison can result from a lack of mental number lines, and students who struggle with mental number lines can benefit from using a concrete number line as a visual cue (Confer, 2005; Holloway & Ansari, 2009). Number lines are a common support used in the secondary education class-

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room as students with intellectual disability perform functional or academic mathematics skills (Browder, Spooner, & Trela, 2011).

There are various mediums of presenting number lines when teaching students with and without disabilities. Paper is the most common medium to present number lines (Fletcher, Boon, & Cihak, 2010). However, computers can also effectively present number lines (Fuchs et al., 2006; Lin, Podell, & Tournaki-Reid, 1994). As computers are increasingly replaced with more mobile devices (e.g., iPad), the potential for numbers lines to be placed on such mobile devices through apps also exists (Herbert, 2010). Mobile devices not only offer the capacity to present instructional materials much like traditional computers, but also provide advantages, such as portability, long battery life, multi-touch capacity screens, and ease of access to numerous apps (Clark & Luckin, 2013; Douglas, Wojcik, & Thompson, 2012). The portability and long battery life of these mobile devices allow students to gain access to instructional materials in multiple settings and for multiple tasks (Vedantham & Shanley, 2012).

Although mobile devices and their apps are presumed to provide many benefits to students with disabilities, research on their potential is lacking. The majority of research on mobile devices focuses on the provision of video modeling to students with disabilities with these devices, rather than evaluating the effectiveness of apps for learning and skill acquisition. However, within the existing limited literature, support exists for use of apps on mobile devices to support individuals with disabilities, including individual with intellectual disability. For example, Cihak, McMahon, Smith, Wright, and Gibbons (2015) successfully taught individuals with intellectual disability to use an email app on an iPad to communicate; Cihak et al. also taught the individuals to send an email via desktop and laptop computers, providing the individuals choice and flexibility of technology medium. In another study, Hsu, Tang, and Hwang (2014) successfully taught three secondary students with moderate intellectual disability to use an app on a mobile device to support purchasing skills.

The purpose of this study is to compare the effects of paper-based number lines and app-based number lines to teach number comparison skills for students with intellectual disability. In this study, the authors compared paper-based and app-based number lines – presented on an iPad – to perform number comparison for students with intellectual disability. This study systematically compared the effectiveness of two number lines for teaching number comparison. Research questions in the current study include the following: (a) Can the effectiveness of number lines be replicated in teaching number comparison for students with intellectual disability?, (b) Are app-based number lines as effective as paper-based number lines in teaching number comparison for students with intellectual disability?, and (c) What are students and practitioners’ perspectives on learning and teaching number comparison via a mobile device?

Method

Participants

Three students with intellectual disability were recruited from a high school in the Midwest. All participating students met the following criteria: (a) identified with a moderate intellectual disability, (b) educated in high-school, (c) Individualized Education Program (IEP) goals related to academic and functional mathematics, (d) ability to identify numbers 0–10, (e) visual and hearing functioning within normal limits before or after correction, and (f) lack of mastery of single-digit number comparison. The first five criteria were judged based on teachers’ reports. The last criterion was assessed using a five-question pre-assessment, which was given to determine the lack of mastery of single-digit number comparison if the students selected target numbers with 0–80% accuracy. All students received academic instruction in a regular classroom at rates less than 40% of the day and functional instruction in the special education classroom at rate of more than 60% of the day.

Seth. Seth (pseudonym) was a 15-year-old, 10th-grade, male student with a moderate intellectual disability. Seth had a Full Scale IQ of 51, Nonverbal IQ of 56, and Verbal IQ of 51, according to the Stanford-Binet Intelligence Scales Fifth Edition (SB-5; Falvo, 2005). His
general adaptive composite score of 69 according to Adaptive Behavior Assessment System (ABAS-II) indicated a moderate disability (Lichtenberger & Kaufman, 2009). Seth was sociable and outgoing, but he also had a short attention span and became easily distracted by others and environmental stimuli. His teacher reported his performance fluctuated daily, and that Sean loved to use iPads.

Helen. Helen (pseudonym) was a 14-year-old, 9th-grade, female student with a moderate intellectual disability. Helen had a Full Scale IQ of 52, Nonverbal IQ of 57 and Verbal IQ of 52 according to SB-5 (Falvo, 2005). Her general adaptive composite score of 40 according to ABAS-II indicated a moderate disability. Helen was typically friendly with staff and peers and she liked to use iPads in school.

Kelsey. Kelsey (pseudonym) was a 14-year-old, 10th-grade, female student with a moderate intellectual disability. Kelsey had a Full Scale IQ of 42, Nonverbal IQ of 46, and Verbal IQ of 43, suggesting a moderate intellectual disability according to SB-5 (Falvo, 2005). Her general adaptive composite score of 41 according to ABAS-II was consistent with a moderate disability. Kelsey was friendly, outgoing, and eager to please teachers; she also liked to be around her peers. The teacher reported Kelsey had experience using iPads in class.

Settings
The study was conducted at a public junior and senior high school in a small room adjacent to students’ main classroom. The small room contained a desk and three chairs. On one wall were a washer and dryer, and on the other wall a storage cabinet. Using the adjacent room for sessions minimized possible distractions from activities in the main classroom. The room arrangement was consistent in the baseline and intervention phases. For the generalization phase, the researchers set up a simulated grocery store in the room. Five pairs of grocery products, each with two different price tags, were set on the table.

Materials
iPad. An Apple iPad 2 was used in the study. The size of an iPad 2 – 9.5 × 7.31 × 0.34 inches – provided sufficient space to display the number line app used in the study. The participating students were familiar with iPads because their classroom had two iPads.

Number line app. The number line app used in the number comparison study was developed byAuthors (2013), who employed theoretical and empirical guidance for developing software and instructional technology for students with disabilities (see Higgins, Boone, & Williams, 2000; Tammaro & Jerome, 2012; Walker, 2011; see Figure 1). The number line app was age appropriate for secondary students and had a consistent layout, simple design, non-distracting items, and easy navigation. At the bottom of the app was a horizontal number line consisting of whole Arabic numerals from 0 to 10 printed in the same-sized font. In the top, left corner were three control buttons: refresh, marker, and eraser icons. When the marker function was on, students used their fingers to circle numerals. When numerals were circled (e.g., 2 and 6), arrays of dots corresponding to the circled numerals appeared above the numerals (e.g., 2 dots and 6 dots). With the eraser function was on, the students used their fingers to erase the circles.

Paper-based number line. The paper-based number line was presented on a laminated letter-size paper. The lamination allowed students to use markers. The number line – located on the bottom of the paper – consisted of a horizontal line with whole Arabic numerals from 0 to 10 printed in the same size. Additionally, there were 11 same-sized strips (6.5” × 0.8”) with different amounts of red dots ranging from no dots to 10 red dots (see Figure 1). The strips were held by the researcher, who added individual strips to the number line when the student circled numerals using a marker. The strips were removed from the number lines by the researcher as soon as the students erased the circles on the number lines using a dry erase board eraser.

Assessment. There were 15 number comparison assessments throughout the baseline and intervention phases and 6 price comparison assessments during the generalization phase. Each number comparison assessment consisted of five questions. The assessments were randomly generated using the website Random.org. Each question contained two whole Arabic numerals between 0 and 10. To
minimize the order effect, the arrangement of the two numerals with different quantities in each question set was randomized. A coin flip was used to determine the order of the two numerals (e.g., the bigger number on the right and the smaller number on the left [e.g., 5 vs. 8]; the smaller number on the right and the bigger number on the left [e.g., 5 vs. 3]), while ensuring that no more than two consecutive sets had the same order of numbers.
Thus, for each assessment – one used per session – only two or three question sets had larger numbers to the right of smaller numerals. Each of the questions were printed on a piece of paper (2” x 8”) in Times New Roman, size 48 font, and presented to each student one-by-one.

**Grocery products.** During generalization, a total of 25 pairs (i.e., 50 items) of grocery items were purchased based on the teacher’s suggestions of items commonly purchased by the students during their weekly shopping. Each pair of the items – containing two brands of the same type of product (e.g., Dawn Dish Soap and Method Dish Soap) – was assigned two different single-digit prices (e.g., $3 and $5). The first author randomly selected five of the 25-paired items for each of the six generalization sessions, each consisting of five trials. Some of the items were repeated twice, but none of the items were repeated more than twice.

**Dependent and Independent Variables**

The independent variable was the use of two types of number lines (i.e., app- and paper-based number lines) in conjunction with a system of least-to-most prompts and a constant time delay for all tasks analyses except for the steps, “say or point to the target number” and “say or point to the lower price tag”. The dependent variables were (a) the percentage of correctly answered number comparison questions per session and (b) task completion time per session.

**Design and Procedures**

A single-subject alternating treatments design study was employed to compare the effects of the two types of numbers lines on teaching number comparison to three students with moderate intellectual disability. An alternating treatments design was selected because it allows comparing two intervention conditions by rapidly alternating instructions (Barlow, Nock, & Hersen, 2009). This alternating treatments design study consisted of baseline, intervention, and generalization phases.

**Baseline.** During each of the five baseline sessions, students worked with the first author one-on-one. Students were presented with five questions, each on a separate piece of paper, one at a time. After giving the student a question, the researcher verbally asked one of the directions: (a) “Which one is bigger?” or (b) “Which one is smaller?” The selection of either oral direction was randomly selected and no more than two consecutive trials with the same direction and no same direction was asked more than three times. All students went through the same order of the oral directions. Two behaviors were recorded: (a) time to complete five questions per session, and (b) percentage of correctly answered questions (either bigger or smaller).

**Training.** During training, the researcher individually taught students how to use the two number lines using a six-step task analysis (see Table 1). Students were first given the paper-based number line, a marker, and an eraser. Students were presented with a pair of numbers on a paper sheet and asked to circle

<table>
<thead>
<tr>
<th>Task Analysis for Intervention</th>
<th>Task Analysis for Generalization</th>
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<tbody>
<tr>
<td>1. Circle 1st number on a number line</td>
<td>1. Circle 1st number on a number line</td>
</tr>
<tr>
<td>2. Circle 2nd number on a number line</td>
<td>2. Circle 2nd number on a number line</td>
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<tr>
<td>3. Say/point to the target number*</td>
<td>3. Say/point to the target number*</td>
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<tr>
<td>4. Circle on the paper problem</td>
<td>4. Say/point which price is smaller*</td>
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<tr>
<td>5. Erase 1st circles on a number line</td>
<td>5. Say/point which price is cheaper*</td>
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<tr>
<td>6. Erase 2nd circles on a number line</td>
<td>6. Erase 1st circles on a number line</td>
</tr>
<tr>
<td>7. Erase 2nd circles on a number line</td>
<td>7. Erase 2nd circles on a number line</td>
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* Do not provide least-to-most prompting.
the two target numbers with the marker on the number line. Within two seconds of when students circled one number on the number line, the researcher placed a strip with an array of dots corresponding to the numbers above the number line. After circling two numbers, students were asked which was smaller (or larger). After students answered and circled the target number on the paper, the researcher instructed students to erase the circles using the erasers and the researcher removed the two strips one by one. The students were given another two opportunities to practice these steps. After two practices, students were given another question sheet to determine the training outcomes. If students reached the criterion of 83.3% accuracy on one question (i.e., five out of six steps, which include manipulating the number line and answering questions; see Table 1), the training for using paper-based number line was considered concluded. All three students reached 100% of accuracy of paper-based number line after the first trial.

Next, students were shown the app-based number line, using the same procedure as with the paper-based number line. Students were first introduced to the app’s marker and eraser icons. Students were then given a piece of paper with a pair of numbers and asked to circle the target numbers. Seth and Helen operated the number line app using their fingers, while Kelsey operated the app with a stylus because the iPad screen was not 100% responsive to her fingers. Once students circled the numbers, the arrays of dots appeared immediately and automatically. After students selected the target number from the number line and then the question sheet, the researcher asked them to press the erase icon and use their fingers or stylus to erase the circle. Once the circles were erased, the dots disappeared immediately. Finally, students were given two more opportunities to use the app-based number line. The same mastery criterion as with the paper-based number line was applied. Seth and Helen reached 100% of accuracy after first trial and Kelsey reached 83.3% accuracy after the second trial using a stylus.

**Intervention.** The intervention phase consisted of 10 sessions – five for each condition (paper-based and app-based number line); students worked one-on-one with the first author. The sequence of the two conditions alternated randomly, with no more than two consecutive sessions of the same condition. During each session, students were given five number comparison questions. After the two numbers were circled on either number line – and their resulting visual array appeared, the researcher verbally asked the student which number was either smaller or larger, as in baseline. Each session concluded once students had completed five questions. The researcher recorded the same target behaviors as in the baseline condition.

**Generalization.** The generalization phase consisted of six sessions – three for each intervention condition. The sequence of the two conditions randomly alternated, so no more than two consecutive sessions were the same condition. During the generalization phase, participating students used either type of number line to select the lower-priced grocery item in a simulated grocery store in the classroom. The procedures in the generalization phase were similar to those in the intervention phase, except the tasks were comparing pairs of different, single-digit prices ($2 vs. $4). Each session consisted of five trials of selecting lower-priced items.

**Social Validity**

Social validity interviews were conducted to assess the use of number lines in learning number comparison and to compare the two types of number lines. Participating students and their special education teacher were interviewed for approximately 10 minutes after the generalization phases. Students and the teacher were each asked nine questions, including open-ended and yes/no questions. The questions for the students included: (a) What do you think about learning to compare numbers?; (b) What do you think about learning to compare prices?; (c) Do you think learning how to compare on a number line will help you solve some questions?; (d) Considering both math questions and comparing prices, what do you think about using the number line?; (e) What do you thing about using the number line on an iPad?; and (f) Which number line did you like using when you go shopping and need to compare
prices? The nine social validity for teachers were: (a) What are the advantages of learning number comparison?; (b) Would you teach number comparison in the manner used in this study?; (c) Do you think your students benefitted from learning number comparison skills?; (d) Do you think your students benefitted from using a number line to learn price comparison skills?; (e) Will you continue to use a number line to teach number-related skills?; (f) What did you like about using a number line presented on paper?; (g) What did you not like about using a number line presented on paper?; (h) What did you like about using a number line presented on an iPad?; and (i) What did you not like about using a number line presented on an iPad? Interviewees’ were encouraged to elaborate on each question.

Interobserver Agreement and Treatment Integrity

Interobserver agreement was evaluated for 33.3% of sessions for each student. The first author served as the main data collector and three other people served as the second observers, including two special education researchers and one paraprofessional. The second observers alternated observing a total of seven sessions for each participant, including two sessions during the baseline phase, three sessions during the intervention phase, and two sessions during the generalization phase. These sessions in each phase were selected randomly. Interobserver agreement on the percentage correct was 100% for Seth and Helen, and 99.8% for Kelsey. Treatment integrity was assessed by the first author and the second observers for 42.9% sessions (i.e., three sessions each in baseline, treatment, and generalization phases) using a checklist. The items in the checklist included the following: (a) researcher places a number line (and marker and eraser if paper) on the desk; (b) researcher starts to time a session; (c) researcher gives a paper problem and provides time delay, (d) if paper, researcher puts down matching array of dots and provides time delay after the student circles the first number on the number line; (e) if paper, researcher puts down matching array of dots and provides time delay after the student circles the first number on the number line; (f) researcher points to arrays and asks which one is bigger/smaller followed by time delay; (g) researcher takes away paper problem followed by time delay; (h) researcher takes away dots if using the paper number line; and (i) researcher stop timing session. Treatment integrity was achieved 100% for all three students.

Data Analysis

Visual and quantitative data for the two types of number lines in the baseline, intervention, and generalization phases were analyzed. In each session, trial recording technique was used to document the responses for each trial (Ayres & Gast, 2010). For each session, the accuracy of the answers was calculated as a percentage, dividing by five the total of correct selections of either the target numbers or the lowest price; these data were then graphed onto line graphs. The duration recording technique was used to note the completion time for each session to compare the efficiency of the two number lines (Ayres & Gast).

Visual analysis techniques were used to analyze level of the graphed data points within and between phases (Gast & Spriggs, 2010; Lane & Gast, 2013). Level stability was determined using the 80%–20% criteria: 80% of data points fall on or within the stability envelope, which is 20% of a median value from a baseline (Gast & Spriggs). The mean accuracy and two types of effect sizes were reported across phases for quantitative data analysis (Maggin, Briesch, & Chafouleas, 2013). First, each student’s mean and range of accuracy in each phase was calculated as a percentage. Second, two effect size indices – standard mean differences (SMD) and regression coefficients – were reported to present the effectiveness of two types of number lines. SMD were obtained using the mean differences between baseline and intervention divided by the standard deviation. Standardized coefficients – one type of regression-based effect sizes – were calculated to present trends and levels separately (Beretvas & Chung, 2008).

Results

For the three students, the visual analysis and SMD indicated both types of number lines were effective. However, the app-based num-
ber line was slightly more effective and resulted in more stable outcomes than the paper-based number line for two of the students. Figure 2 displays the accuracy of the number comparison performed and Table 2 summarizes the mean, level stability, SMD, and standardized regression coefficients for trends and levels, and completion time for each student.

Seth
During the baseline phase, Seth correctly answered an average of 76% of the questions, with sessions ranging from 40 to 100%. Seth’s data points showed a variable level as only 60% data points within the stability envelope. During the intervention phase, Seth correctly answered 100% of questions with zero-celerating trend and stable level (100% data points within the stability envelope) under both the paper- and the app-based number line conditions. Both Seth’s SMD for the paper- and the app-based number line conditions were 1.24, indicating both number lines demonstrated positive effects. Regarding completion time during the intervention phase, Seth took 51 seconds longer, on average, to complete all questions per session under the paper-based number line condition than the app-based number line condition (5:44 vs. 4:53). During the generalization phase, Seth selected the lower-priced item with 100% accuracy with stable trend and level (100% data points within the stability envelope) under both number line conditions. He took, on average, 55 seconds longer to complete questions using the app than the paper-based number line condition during generalization.

Helen
During baseline, Helen correctly answered an average of 52% of questions, with range from
20% to 60% with stable level (80% data points within the stability envelope). During the intervention phase, Helen performed slightly more accurately using the app-based number line. She correctly answered 96% of questions on average per session under the paper-based number line condition with stable level (80% data points within the stability envelope) but 100% under the app-based number line condition with stable level (100% data points within the stability envelope). Both conditions were effective for Helen judged from effect size indices: SMD (i.e., 1.64 under the paper-based condition; 1.72 for the app-based condition) and the standardized regression coefficient for level (i.e., 1.26 under the paper-based condition, \( p < 0.01 \); 1.36 for the app-based condition, \( p < 0.01 \)). On average, Helen took 1 minute and 45 seconds longer to complete a session under the paper-based than the app-based number line condition (4:58 vs. 3:13, respectively). During the generalization phase, she selected the lower-priced item with 100% accuracy with a zero-celerating trend and stable level under both number line conditions. She took an average of 1 minute and 12 seconds longer to complete a session under the paper-based than the app-based number line condition.

Kelsey

During baseline, Kelsey correctly answered an average of 52% questions, with a range from 40% to 80% with cyclically variable trend (Gast & Spriggs, 2010) and variable level (60%...
data points within the stability envelope). During the intervention phase, she performed better under the app-based number line condition. She correctly answered an average of 80% of questions per session under the paper-based number line condition and 92% under the app-based number line condition. Kelsey’s data points under the paper-based number line condition showed cyclically variable trend and variable level (20% level stability) across sessions. Her data under the app-based number line showed zero-celerating trend and stable level across four sessions (sessions 7, 10, 11, and 14) and then decelerating for the last session (session 15), resulting in 80% level stability. The effect size indices also indicated the superior effect of the app-based number line over the paper-based number line: SMD (1.48 [app] vs. 1.21 [paper]) and the standardized regression coefficient for level (1.09, p = .051 [app] vs. .46, non significant [paper]). On average, Kelsey took 2 minutes and 44 seconds longer to complete a session under the app-based condition as compared to the paper-based number line condition. During the generalization phase, she performed faster in the app-based number line condition (5:22 vs. 5:53, respectively). She selected the lower-priced item with 47% accuracy under the paper-based number line condition and 87% accuracy under the app-based number line condition.

Social Validity
All the students and the teacher indicated they liked using the number lines to learn and teach number and price comparison. Helen stated the number lines helped her compare numbers. In terms of medium preference, Seth and Helen chose the app-based, and Kelsey chose the paper-based number line. For likes and dislikes about the paper number line, Seth said he liked that he could draw circles on it. However, he disliked several aspects of it, including that he thought it was hard to circle the numbers, the eraser kept falling to the floor, and he did not like that his hands got dirty while using a marker. Helen expressed similar dislikes. Kelsey did not elaborate on her likes and dislikes about the number lines. The teacher thought the paper-based number line could be used as a teaching tool instead of using iPads; paper is more beneficial for students who experience challenges with fine motor skills. She stated, however, that the paper-based number line could carry a greater stigma for students using them.

Regarding the app-based number line, Seth said he liked everything about it, especially that he could operate the number line using just his finger. Helen liked that she could carry an iPad wherever she went. She thought using the app-based number line helped her solve problems faster, and she liked that did not need an adult sitting next to her as she did under the paper-based number line condition. The teacher believed using iPads offered less stigmatization. Seth, Helen, and the teacher all liked the multifunctional quality of iPads.

Discussion
The main purpose of this study was to compare the effectiveness of two types of mediums used to present a number line to secondary students with intellectual disability: an app-based number line and a paper-based number line. The app-based number line was equally effective as, if not slightly more effective than, the paper-based number line in terms of accuracy and task completion time during number comparison (intervention) and price comparison (generalization) tasks.

The study shows use of a number line was effective in teaching number comparison. Comparing the means of the baseline and treatment phases, the three students were more accurate when using a number line than not using one. The use of a number line benefited even Seth, who achieved 76% accuracy in baseline. By visually examining Seth’s data points, we found his performance on number comparison fluctuated during the baseline phase, with a range from 40% to 100%. However, his performance became stable when he used either number line. Seth consistently achieved 100% accuracy independently under both number line conditions. While we could not isolate the factors causing his performance to fluctuate during the baseline phase, we conclude use of a number line prevented the fluctuation during intervention. Seth successfully executed number comparison tasks.
with the support of a number line; success with number comparison, supported or unsupported, allows students to engage in the application of academics and functional mathematics (Holloway & Ansari, 2009; Storey & Miner, 2011).

The results were inconsistent regarding the average task completion time under duration the app and paper number line conditions. For Seth, his average tasks completion time using the app number line was about 50 seconds faster than using the paper-based number line during the intervention phase, and 50 seconds slower under the generalization phase. For Kelsey, the situation was reversed. Kelsey was about 2 minutes and 45 seconds slower when using the app number line during the intervention phase. However, during the generalization phase, she was about 30 seconds faster, on average, using the app-based number line. Helen completed the tasks faster with the app number line in both intervention and generalization phases. However, it should be noted that the difference in time, especially with regards to the paper number line, could be based on design. For example, with the paper number line the researcher had to place on the dots, and the students had to maneuver multiple objects (e.g., eraser and pen). With the exception of Kelsey during intervention, the differences between the two conditions were all less than two minutes.

Although both interventions were equally effective for Seth, the app-based number line was slightly more effective than the paper-based number line for Helen and Kelsey. The difference between app and paper was relatively minor for Helen during intervention (i.e., 96 vs. 100% accuracy), but larger for Kelsey during the treatment phase (i.e., 80 vs. 92% accuracy) and the generalization phase (i.e., 46.7 vs. 86.7% accuracy). In this study, the app-based number line was presented on a mobile tablet, specifically the iPad. One hypothesis for the difference in performance for the two female students between the app-based number line and the paper-based number line involved the design of the study. The app-based number line simplified the objects to manage during the task, as all were virtual and contained within one device. Under the paper-based number line condition, participants were required to hold three items, including the number line, an eraser, and markers, and to make certain these items did not fall from the clipboard. This was a limitation of the study. The authors felt this hypothesis might be more applicable to Kelsey given her hand motor control was less developed and she tended to drop objects more than the other students, which may have compromised her working memory and attention to the tasks (Low, Jin, & Sweller, 2011), although it did not impact her task completion time during intervention (i.e., faster with paper than app number line during intervention). However, the authors could have, and teachers can, make the paper-based number line more efficient by using dry erase markers with an eraser pad on and end and attaching the marker to a clipboard via string.

Clearly, both number line options provided advantages to students and teachers should consider using at least one, if not both. Both types of numbers line provide advantages and disadvantages to students and teachers, and teachers to consider their context and individual student preferences as well as strengths and challenges when making such decisions. In terms of the app-based number line, it offers greater independence and less adult-required assistance, when using a number line with dots for additional visual cues (i.e., the researcher had to manually apply the dots). Based on the structure of the paper-based number line in this study, the app-based number line provide more convenience with less things to hold as well as the potential for greater portability within community-based settings, including the potential or less stigmatization when using an iPad in a grocery store than a number line on a clipboard. However, mobile devices, such as iPads, are more expensive than make a laminated paper-based number line. In addition, teachers need to be cognizant regarding the fragileness of these devices, particularly as compared to a paper-based number line. While a protective case can help to reduce breakage, a potential concern remains.

As noted, student preference is important, especially when considering technology. Technology abandonment is a real concern for students with disabilities, and taking student consideration into account can reduce
the potential for abandonment, which does not only cost money but also leaves students without assistance (Parette & Scherer, 2004). Two of the students preferred the app-based number line to the traditional medium in this study and one preferred the paper-based number line. Despite the appeal of apps and mobile devices (i.e., more sophisticated technology), student preference in actual learning situations to new technology is not always found (Bouck & Weng, 2014; Woody, Daniel, & Banker, 2010). Educators need to ensure that students are comfortable with the medium of their learning, regardless of low-tech or high-tech.

**Implications for Practice**

There are several practical implications that arise from this study. First, secondary special education teachers should continue to incorporate a number line of any type into their teaching to help students with number comparison. The students were more successful in correctly comparing single digit numbers with either number line condition than without. For students without a consistent mental number line, paper or app-based number lines can support this skill in both basic and applied (i.e., grocery shopping) situations. The second implication is that teachers should not discard a paper-based number line just because the app-based number line presented on the mobile device demonstrated a slightly better effect for two of the students. The paper-based number line was an effective intervention. As the special education teacher indicated in her social validity interview, the paper-based number line should be introduced to students because it is a cheaper and more readily available medium to use in classroom settings. However, teachers may also wish to incorporate innovative ways to presenting a number line, such as using an app-based option. Use of the number line app on a mobile device can offer a more efficient and socially-acceptance means of supporting students in non-classroom settings.

**Limitations and Future Directions**

This research study, like all research studies, involves limitations. The first limitation is the possible multiple-treatment interference inherent in an alternating treatments design. Given the anticipation of the possible treatment interference, researchers applied methodical strategies (i.e., randomizing the sequence of administering the two conditions and administering only one treatment condition per session) to minimize the possible effects. Future studies should add the best treatment phase (i.e., a phase where the superior condition within the intervention phases was applied) to the design. If the superior condition continued to demonstrate its effect during the best treatment phase, one could rule out the interference effect of two treatment conditions. Researchers may also want to conduct an alternating treatments design with a multiple baseline in the future to provide greater confidence in experimental control.

A second limitation is the possibility of novelty effects produced by an engaging tool such as an iPad. The authors considered this possibility (i.e., novelty effect when using iPads) in the design of the study and attempted to limit such an effect by making the two number lines as similar as possible. However, the interactivity of the iPad as well as its socially-desirable nature are difficult to control for when comparing to paper-based alternatives. Another limitation involved that the stimuli used in this study were single-digit numeral comparison using an adapted number line containing only 0 to 10 digits. Learning how to compare single digits apparently will not be sufficient because secondary students with disabilities are more likely to encounter multi-digit numeral comparison in academic settings and the real world. Therefore, future studies need to look into whether the adapted numbers are suitable for comparing multi-digit comparison using numeral comparison strategies, such as the decomposition model.

Finally, both the app-based and paper-based number lines used in this study contained non-symbolic number cues (i.e., arrays of dots). It appears that the non-symbolic number cues were effective in facilitating number comparison tasks; however, the study did not directly investigate the effects of non-symbolic numeral cues by comparing it to a controlled condition (e.g., number line without the non-symbolic number cues). Researchers need to empirically examine the effect of the non-
symbolic number cues by directly comparing number lines with and without these non-symbolic cues for students with intellectual disability. In addition, the non-symbolic number cues only presented to students when a numeral was selected. Future research can also examine the presentation of additional visual cues by comparing: (a) all non-symbolic number cues shown above a number line consistently, and (b) non-symbolic number cues presented only when associated numerals are selected.

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