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# Print to Braille: Preparation and Accuracy of Mathematics Materials in K-12 Education

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***Structured abstract:*** *Introduction:* This study analyzed the accuracy of 107 mathematics worksheets prepared for tactile learners. The mean number of errors was calculated, and we examined whether there was a significant difference in the level of accuracy based on National Library Service for the Blind and Physically Handicapped (NLS) certification or job role of participants. *Methods:* The authors selected five work sheets representative of mathematics materials transcribed for K-12 students. After completing an online demographic survey, participants prepared at least one of the worksheets and completed an online transcription survey about how they prepared each worksheet. *Results:* The majority of the 59 participants spent less than 30 minutes transcribing each worksheet, and the predominant method for production was the use of braille translation software. Overall, participants had a high level of accuracy on the literary braille portions of the worksheets. There was variability in the accuracy of the Nemeth elements, formatting, and tactile graphic labels across the transcriptions. Significant differences existed between the means of errors in formatting and literary braille according to NLS certification status and, to a lesser extent, job role. There was not a significant difference in the accuracy of Nemeth elements in the majority of the worksheets according to certification status or job role. There were no significant differences in the preparation of the worksheets based on primary production method. *Discussion:* There was variability in how materials were prepared for tactile readers and in the quality of the transcriptions. *Implications for practitioners:* Variation in how materials are presented to tactile readers, including the formatting of headings and directions, can affect the ease of scanning and reading of materials. Inconsistencies, omissions, and errors have the potential to impact the ability of readers to understand and access information.

The Nemeth Braille Code for Mathematics and Science Notation (hereafter, referred to as Nemeth code) is used when transcribing technical material that includes mathematical equations or scientific notation (Laudenslager, 1972). This code provides a system of symbols and detailed prescriptive procedures so that mathematics and science materials from elementary to the most advanced levels can be uniformly represented and read in

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braille (Laudenslager, 1972). There are braille equivalents for hundreds of mathematical and scientific symbols, signs, numerals, and variables. The inclusion of tactile graphics allows critical information in figures, charts, graphs, and diagrams to be provided to readers (Braille Authority of North American [BANA], 2010). Similar to the literary and Nemeth codes, there are guidelines to carefully consider when creating tactile graphics. Tactile graphics communicate the ideas and information; they are not replicas of the visual depiction in a tactile form (American Printing House for the Blind [APH], 2008; BANA, 2011). Poorly designed or cluttered tactile graphics present challenges to readers and may not support them in building or understanding concepts (Zebehazy & Wilton, 2014).

Consistent and uniform formatting allows a reader to easily navigate and read materials in the literary and Nemeth braille codes. Formatting in braille is highly structured, and consistent formatting permits readers to detect information quickly by scanning the page with their hands (Texas School for the Blind and Visually Impaired, 2010). Thus, it follows that consistent formatting may actually improve overall readability of braille documents. In contrast, inconsistent or incorrect formatting can slow the reader down and lead to frustration (Damm & Risjord, 2008).

Incorrect application of rules affects the accuracy of the transcription of materials using Nemeth code. For example, without the proper use of an English letter indicator, a combination of letters such as *ab* or *cd* representing a line might be confused with the words *about* or *could*. Depending on how and where a braille symbol is used in mathematics braille transcription, the dots 2, 3, 6 can represent the numeral 8, the word *his*, the left outer quotation mark, or the question mark. The one-cell lower-sign whole-word contraction for *his* cannot be used when it is in direct contact with a grouping symbol (Laudenslager, 1972). If the contraction for *his* was used incorrectly following a grouping symbol, the dots would be read as the numeral 8. Errors such as this could easily cause misunderstanding or confusion as well as affect the usability of the materials in the general education classroom.

Our study focused on the preparation of mathematics materials for braille readers. In the first part of the study, demographic information was collected for 166 participants. These data were reported in Rosenblum and Herzberg (2011). The 166 participants represented a variety of personnel, including certified braille transcribers, noncertified braille transcribers, paraeducators, and teachers of students with visual impairments. Training experiences and perceived level of preparedness varied greatly, and slightly more than a quarter of the 166 participants were certified by the National Library Service for the Blind and Physically Handicapped (NLS), Library of Congress. The 166 participants were each invited to participate in the second part of the study.

The purpose of the second part of the study was to examine techniques used by participants in preparing mathematics worksheets for tactile learners, explore the accuracy of the transcriptions, including the frequency and types of errors, and determine if tactile graphics were included. It was hoped that identifying frequency and types of errors would allow pre-service and in-service trainers to address the error patterns and would, hopefully, prevent similar types of errors in the future. The following research questions were explored:

1. What tools were used and how long did it take to prepare the transcriptions?
2. How accurate was the braille transcription of the print materials?
3. Were tactile graphics included on the transcriptions when needed to provide critical information to the braille reader?
4. To what extent were the rules of the Nemeth code and guidelines for tactile graphics followed?
5. To what extent were the rules for formatting mathematics materials in Nemeth code followed?
6. Were there patterns of errors in the transcriptions?
7. How did participant variables, including job role and NLS certification, relate to the frequency of errors that were made?

## Methods

Approval to conduct the research was obtained from the Institutional Review Board at the University of South Carolina Upstate.

### Procedure

The authors reviewed a variety of commercially designed print and teacher-produced print mathematics workbooks and worksheets across grade levels before selecting five worksheets. The first-grade worksheet contained 27 single-digit addition problems. The third-grade worksheet included a simple word problem, two-digit spatially aligned addition problems, and four problems that included critical information in graphics. The fifth-grade worksheet included nine problems that requested students to classify shapes or find the missing angle. The last problem showed a flag and asked students to classify colored parts of it. The algebra worksheet began with three problems that included lines on a coordinate plane. The eight following questions asked students to write equations with the given information. The geometry worksheet consisted of six unnumbered problems. Two problems focused on rotating shapes on a coordinate plane, and the other four problems required students to calculate the area and perimeter of trapezoids and triangles.

After participants completed the demographic survey (See Rosenblum and Herzberg, 2011) they were invited to follow a link to a website that contained five scenarios about tactual learners. The scenarios were developed by the authors, and each of the five described a child being in a general education classroom in which the class was completing an activity with the specific worksheet. Participants were invited to read the scenarios, and then to select and prepare at least one worksheet associated with a scenario. There were no guidelines regarding the selection process; participants were free to choose which scenario or scenarios to use and were not limited to a number of worksheets they could prepare. Participants were instructed to prepare the worksheet using any method that was typical for them.

After preparing a worksheet in hard copy braille, the participant completed an online transcription survey about the preparation of the specific worksheet. A transcription survey was completed for each worksheet prepared. Questions on the transcription survey asked about the amount of time participants spent in preparing and producing the worksheet, production method or methods utilized, resources used in the preparation, and proofreading of the worksheet either visually or tactually. The hard copy brailled worksheets were mailed to the first author via postal mail.

### Data analysis procedure

We created a detailed codebook for each of the five worksheets. We used the *Braille Handbook for the Nemeth Code of Mathematics and Science Notation* (Laudenslager, 1972); *An Introduction to Braille Mathematics* (Roberts, Krebs, & Taffet, 1978); *Guidelines and Standards for Tactile Graphics* (BANA, 2010); and *Braille Formats: Principles of Print-to-Braille Transcription* (BANA, 2011) as references when creating the codebooks. We then began coding all elements of the worksheets. For example, on the first-grade worksheet, for each addition problem we recorded whether the problem was brailled in linear format or spatial format Also, we recorded the use of the numeric indicator in linear formatted problems and the proper use of the separation line in spatially formatted problems. We then grouped individual elements into one of the following seven categories: literary, Nemeth code, combined literary and Nemeth codes, graphics, transcribers' notes, formatting, and other. We reserved the category of combined literary and Nemeth for items that contained words and mathematical items. For example, on the third-grade worksheet we placed the item "How many toes do 9 children have altogether?" in the combined literary and Nemeth category because the "9" follows Nemeth rules (for instance, use of the numeric indicator, number in the lower part of the cell) but the "9" is interspersed with literary words.

The two authors collaboratively scored a sample transcription to assure the coding categories and procedures were clearly defined. Then all elements on 20 transcriptions were independently reviewed and coded by both authors. A frequency count of agreement or non-agreement of the two authors was used to calculate the reliability percentage. The reliability of the two authors across the 20 transcriptions was 95%. Any nonagreements were discussed, and the coding scheme was refined. The first author then coded the other 87 transcriptions. All data were entered into SPSS statistical analysis software.

### Participants

The 166 participants for the original study were recruited in spring 2010 through an e-mail message posted on electronic discussion groups in the field of visual impairment and to graduates who had completed their preparation as teachers of students with visual impairments at the universities where the authors were employed. Individuals who were currently preparing, or had prepared within the past three years, mathematics materials using the Nemeth code for tactile learners from preschool through grade 12 were eligible to participate. All 166 individuals who

 

*Table 1*
**Number of participants by NLS certification and job role for five worksheets.**

| Worksheet | Number of participants completing the worksheet | NLS certified | Not NLS certified | TVI | Transcriber | Paraeducator and transcriber | Paraeducator |
|---|---|---|---|---|---|---|---|
| First grade | 32 | 10 | 22 | 10 | 7 | 7 | 8 |
| Third grade | 22 | 12 | 10 | 6 | 10 | 2 | 4 |
| Fifth grade | 21 | 12 | 9 | 4 | 9 | 4 | 4 |
| Algebra | 18 | 8 | 10 | 6 | 6 | 3 | 3 |
| Geometry | 15 | 8 | 7 | 4 | 8 | 0 | 3 |

Note: NLS = National Library Service; TVI = teacher of students with visual impairments.

completed the initial online demographic survey (see Rosenblum & Herzberg, 2011) were invited to participate in the second part of the study. The invitation was extended after they completed the online demographic survey via a link to a website.

## Results

Fifty-nine individuals transcribed into braille 107 worksheets and completed the accompanying transcription survey. Fifty-eight participants were female, and one was male. The participants were asked to identify their job titles. In the original survey, the terms *braillist*, *transcriber*, and *paraprofessional* (also known as *paraeducator)* were not defined. Eighteen (30.5%) reported that they were teachers of students with visual impairments, 22 (37.3%) were transcribers or braillists, 9 (15.3%) were both transcribers and paraeducators, and 10 (16.9%) were paraeducators. The authors chose to use the term *transcriber* to refer to individuals who selected either braillist or transcriber as their job role in the original survey. The teachers of students with visual impairments prepared 29 worksheets, the transcribers prepared 40 worksheets, the transcribers-paraeducators prepared 16 worksheets, and the paraeducators prepared 22 worksheets. Participants were asked to identify if they had NLS certification and if so, in what area (for instance, literary, Nemeth). Table 1 provides a breakdown by NLS certification and job role of how many participants prepared each worksheet.

Twenty-four (40.7%) of the participants were NLS certified. Seventeen were certified in literary code only; five in literary and Nemeth codes; one in literary, Nemeth, and textbook format; and one in literary and textbook format. Of the 24 NLS-certified participants, two were teachers of students with visual impairments, three were transcribers-paraeducators, one was a paraeducator, and the remaining 18 were transcribers. Fifty of the 107 worksheets were prepared by individuals with one or more NLS certifications. In comparison with the larger group of participants from the first part of the study (Rosenblum & Herzberg, 2011), a higher percentage of participants in this second part were NLS certified (27%, and 40%, respectively), and fewer were teachers of students with visual impairments (48% and 30%, respectively).

Braille translation software was used to prepare 80% ($n$ = 86) of the transcriptions; 103 (96.3%) of the transcriptions were visually proofread; and 55 (51.4%) of the transcriptions were produced in less than 30 minutes. The most commonly used references were *An Introduction to Braille Mathematics* (Roberts et al., 1978) (*n* = 22) and the *Nemeth Code Reference Sheet for Basic Mathematics* (APH, n.d.) (*n* = 18). The majority of the tactile graphics on the transcriptions were produced using the collage method, though some were produced by other methods such as computer generation or microcapsule. The size of graphics transcribed by participants varied from a full page to small enough for nine graphics to fit on one page.

### Accuracy of braille

Less than 5% of the worksheets were error free. On the other hand, some of the worksheets contained more than two dozen errors. Errors are reported by category below, rather than a count of errors per worksheet.

#### *Literary*

Table 2 provides information about the mean and standard deviation of errors in literary braille elements on the different worksheets for all participants, participants certified by NLS, and participants' job role. The mean of literary braille errors on the five worksheets by all participants ranged from 0.40 to 1.29. Overall, participants had a very high level of accuracy on the literary braille portions of the worksheets. Errors observed on literary elements included adding and omitting words and punctuation. Other errors involved misspelling words and not using part-word signs in words.

#### *Nemeth code*

Table 2 also provides similar information for the different worksheets regarding Nemeth elements. The mean of Nemeth errors on the five worksheets by all participants ranged from .84 on the third-grade worksheet to 5.22 on the first-grade worksheet. Frequent errors on Nemeth elements included using literary numbers instead of Nemeth numbers; not using the punctuation indicator between a number and the period when numbering problems; and using the literary sign instead of the Nemeth sign for the hollow dot indicating degrees. Less frequently occurring errors included misconfigured numbers, omission of mathematics problems, incorrect use of the English letter indicator, and incorrect configuration of the long dash.

#### *Literary and Nemeth codes*

All five worksheets contained elements that included both literary and Nemeth components (see Table 2). The mean for errors on combined literary and Nemeth elements across the five worksheets by all participants ranged from 0.93 on the geometry worksheet to 4.00 on the third-grade worksheet. The most common error on combined elements was using literary numbers instead of Nemeth numbers. Less common errors included: misspelled words, not using a punctuation indicator between a number and a punctuation mark, misconfigured letters, and omitting words and punctuation.

#### *Formatting*

All of the worksheets included formatting elements. The mean for formatting errors on the five worksheets by all participants ranged from 1.35 on the first-grade worksheet to 7.24 on the fifth-grade worksheet (see Table 2). Frequently occurring errors included not centering headings,

 

*Table 2*
**Mean and standard deviation of errors for all participants, participants certified by National Library Service, and job role of participants.**

| Category | Range of errors | All participants | NLS certified | Not NLS certified | TVI | Transcriber | Paraeducator and transcriber | Paraeducator |
|---|---|---|---|---|---|---|---|---|
| Literary | | | | | | | | |
| First grade | 0–4 | 0.78 (1.21) | 0.70 (1.33) | 0.82 (1.18) | 0.80 (1.23) | 0.57 (1.51) | 0.86 (1.46) | 0.88 (0.83) |
| Third grade | 0–5 | 1.29 (1.68) | 0.18 (0.60) | 2.50 (1.65) | 2.00 (1.78) | 0.00 (0.00) | 1.50 (2.12) | 3.00 (1.41) |
| Fifth grade | 0–3 | 0.67 (0.97) | 0.67 (1.15) | 0.67 (0.71) | 1.00 (0.81) | 0.22 (0.44) | 1.00 (1.41) | 1.00 (1.41) |
| Algebra | 0–4 | 1.00 (1.28) | 0.38 (0.74) | 1.50 (1.43) | 0.50 (5.45) | 0.16 (0.41) | 2.33 (0.58) | 2.33 (2.09) |
| Geometry | 0–3 | 0.40 (0.83) | 0.13 (0.35) | 0.71 (1.11) | 1.00 (1.41) | 0.12 (0.35) | NA | 0.33 (0.58) |
| Nemeth | | | | | | | | |
| First grade | 0–47 | 5.22 (11.07) | 0.00 (0.00) | 7.60 (12.73) | 3.60 (7.62) | 0.00 (0.00) | 13.85 (18.05) | 4.25 (9.03) |
| Third grade | 0–3 | 0.84 (1.27) | 0.25 (0.87) | 1.10 (1.45) | 1.33 (1.56) | 0.00 (0.00) | 0.00 (0.00) | 1.50 (1.32) |
| Fifth grade | 0–18 | 1.80 (3.96) | 0.75 (1.35) | 3.22 (5.72) | 1.50 (1.73) | 0.67 (1.32) | 6.00 (8.12) | 0.50 (1.00) |
| Algebra | 0–38 | 4.22 (8.84) | 2.38 (2.07) | 5.70 (11.78) | 1.17 (2.86) | 3.00 (2.00) | 13.00 (21.66) | 4.00 (4.00) |
| Nemeth | NA | NA | NA | NA | NA | NA | NA | NA |
| Nemeth and literary | | | | | | | | |
| First grade | 0–8 | 1.72 (2.3) | 0.60 (1.58) | 2.47 (2.42) | 2.33 (1.86) | 0.71 (1.89) | 2.60 (3.71) | 1.57 (1.71) |
| Third grade | 1–17 | 4.00 (4.19) | 1.83 (1.33) | 6.60 (5.00) | 5.17 (4.16) | 2.00 (1.41) | 9.50 (10.60) | 4.50 (3.70) |
| Fifth grade | 0–11 | 1.62 (2.62) | 0.91 (1.24) | 2.56 (3.64) | 3.50 (5.06) | 0.77 (1.20) | 1.75 (2.87) | 1.50 (1.00) |
| Algebra | 0–7 | 2.22 (2.18) | 1.12 (1.55) | 3.10 (2.29) | 2.67 (1.87) | 1.50 (1.64) | 2.33 (4.04) | 2.67 (2.51) |
| Geometry | 0–3 | 0.93 (1.07) | 0.43 (0.77) | 1.43 (1.13) | 0.67 (1.15) | 0.62 (0.92) | NA | 2.00 (1.00) |
| Formatting | | | | | | | | |
| First grade | 0–2 | 1.35 (0.55) | 1.10 (0.32) | 1.47 (0.60) | 1.56 (0.53) | 0.00 (0.00) | 1.29 (0.49) | 1.50 (0.76) |
| Third grade | 0–11 | 2.50 (2.89) | 1.50 (1.38) | 3.70 (3.72) | 3.67 (3.77) | 1.50 (1.50) | 1.00 (1.41) | 4.00 (4.08) |
| Fifth grade | 0–15 | 7.24 (4.87) | 5.42 (4.50) | 9.67 (4.44) | 11.50 (3.70) | 5.11 (3.98) | 4.00 (4.83) | 11.00 (2.83) |
| Algebra | 0–11 | 4.39 (3.92) | 1.12 (1.12) | 7.00 (3.30) | 8.16 (3.76) | 1.17 (1.17) | 3.33 (3.05) | 4.33 (2.51) |
| Geometry | 0–6 | 2.73 (1.87) | 1.25 (1.03) | 4.42 (0.79) | 4.50 (1.30) | 1.37 (1.30) | NA | 4.00 (0.00) |
| Tactile graphics labels | | | | | | | | |
| First grade | NA | NA | NA | NA | NA | NA | NA | NA |
| Third grade | 0–13 | 2.57 (4.68) | 2.17 (4.01) | 3.11 (5.64) | 1.60 (2.07) | 0.80 (2.52) | 12.50 (0.71) | 3.25 (6.50) |
| Fifth grade | 0–26 | 5.52 (8.86) | 3.67 (7.48) | 8.00 (10.32) | 17.00 (10.98) | 2.89 (5.94) | 4.75 (8.85) | 0.75 (0.50) |
| Algebra | 0–10 | 2.89 (3.21) | 2.50 (3.11) | 3.20 (3.43) | 3.17 (3.18) | 2.00 (2.45) | 3.67 (3.21) | 3.33 (5.77) |
| Geometry | 0–21 | 9.33 (7.35) | 9.37 (7.33) | 9.30 (7.98) | 15.75 (4.28) | 7.88 (7.45) | NA | 4.67 (5.89) |

Note: NA = not applicable; NLS = National Library Service; TVI = teacher of students with visual impairments.

beginning unnumbered directions in cell 1 (instead of cell 5), beginning runover lines in directions in cell 1 (instead of cell 3), and omitting the print page number in the braille transcription of the third-grade worksheet.

### *Labels on tactile graphics*

The five worksheets contained a total of 23 graphics with critical information. In addition, there were three pictures on the first-grade worksheet that did not pertain to the mathematics problems. Eighteen of the 23 graphics required inclusion of labels. Labels on the graphics included letters and numbers such as angle measurements and numbers on a clock face. Participants transcribed all label elements 94.4% of the time, some of the label elements 4.3% of the time, and completely omitted label elements 1.3% of the time. If a shape had four sides labeled and the participant only labeled three of the sides, then the element was coded as transcribed some of the time. The mean for errors on the labels on tactile graphics for the four worksheets by all participants ranged from 2.57 on the third-grade worksheet to 9.33 on the geometry worksheet (see Table 2). Common errors included: using numeric indicators when labeling a thermometer, using an English letter indicator when labeling a vertex of a shape with a capitalized letter, and not using an English letter indicator when labeling a vertex of a shape with a lowercase letter.

## Statistical differences

*T*-tests were conducted to determine if statistical differences existed between the number of errors on the transcriptions of participants who were NLS certified and those who were not certified. The Welch version of the *t*-test was used when variances were not equal. No significant differences were found in the categories of accuracy of tactile graphic labels. The only significant difference between the groups in regard to Nemeth elements was on the first-grade worksheet ($t[21.0] = -2.80$, $p < .001$). With regard to formatting, significant differences existed between the groups on the first-grade, fifth-grade, algebra, and geometry worksheets: $t(28.5) = -2.28$, $p = .030$; $t(19.0) = -2.15$, $p = .044$; $t(11.5) = -5.26$, $p < .001$; $t(13.0) = -6.61$, $p < .001$, respectively). Significant differences were also found for the groups on combined literary and Nemeth categories on the first-grade, third-grade, and algebra worksheets ($t[23.0] = -2.14$, $p = .042$; $t[10.0] = -2.93$, $p = .015$; $t[16.0] = -2.108$, $p = .050$, respectively) as well as on the literary category on the third-grade and algebra worksheets ($t[11.1] = -4.20$, $p = .001$; $t[14.0] = -2.14$, $p = .05$, respectively). In examining the means between the NLS- and non-NLS-certified participants, the NLS-certified participants made fewer errors than the non-NLS-certified participants for every category for which there was a significant difference reported.

*T*-tests were conducted to determine if statistical differences existed between the number of errors on the transcriptions of participants who prepared their transcriptions with braille translation software and those who prepared their transcriptions with a Perkins braillewriter. No significant differences were found among the groups on any of the five worksheets for any category.

One-way analyses of variance (ANOVAs) were used to evaluate mean differences among job roles across the categories on the worksheets. No significant differences related to job roles were found in the categories of accuracy of Nemeth elements and combined literary and Nemeth elements. Regarding literary elements, the one-way ANOVA revealed a significant difference on the third-grade and algebra worksheets ($F[17 = 6.39$, $p = .004$; $F[14] = 6.53$, $p = .005$, respectively). Post hoc Tukey tests indicated that the transcribers were more accurate than other job role groups on the third-grade worksheet. Post hoc Tukey tests also indicated that the transcribers were more accurate than the paraeducator-transcribers ($p = .022$) and the paraeducators ($p = .030$) on the algebra worksheet.

With regard to formatting, the ANOVAs revealed significant differences among the groups on the fifth-grade, algebra, and geometry worksheets ($F[17] = 4.58$, $p = .016$; $F[14] = 6.477$, $p = .006$; $F[12] = 11.40$, $p = .002$, respectively). There were no significant post hoc differences for the fifth-grade or geometry worksheets. Post hoc Tukey tests indicated that on the algebra worksheet the transcribers were more accurate than the teachers of students with visual impairments ($p = .003$).

ANOVAs for tactile graphics labels revealed significant differences for the third-grade worksheet ($F[17] = 6.60$, $p = .004$). Post hoc Tukey tests indicated that on the third-grade worksheet the transcribers were more accurate than the paraeducator-transcribers ($p = .002$), the paraeducators were more accurate than the paraeducator-transcribers ($p = .003$), and the teachers of students with visual impairments were more accurate than the paraeducator-transcribers ($p = .007$).

## Adherence to guidelines for tactile graphics

### *Inclusion of graphics*

According to BANA (2010), tactile graphics should be included if the reader will need the information in order to answer questions or complete a task. There were a total of 23 graphics on the five worksheets. All but seven of the graphics containing critical information were produced by participants.

### *Position of graphics*

When participants did include the graphics, in 88.7% of the instances the braille graphic had the same page orientation as the print graphic, which is what is wanted for accuracy of presentation. When included, participants transcribed all the elements such as dashed lines on a graphic 84.0% of the time. When elements were included, they were positioned properly 100% of the time.

Graphics should be placed near the corresponding problem or at the end of the print page if needed (BANA, 2010). In addition, graphics should be placed near the left margin of the page, not centered (BANA, 2010). Just over a fourth (27.3%) of the tactile graphics on the transcriptions were placed on a separate page with no other graphics or braille material. Some of these pages were included immediately following the problem, and others were placed at the end of the transcriptions. Some of these graphics were placed at the top of the page and others were centered on the page. When graphics were placed on the same page as the corresponding problem, 19% of the graphics were placed near the left margin, and 40.0% of the graphics were centered on the page. In the remainder of the transcriptions, graphics were placed in a variety of locations on the page such as the right side of the page, at the bottom of the page, or indented.

#### *Placement of labels on tactile graphics*

Several print graphics on the fifth-grade worksheet contained angle measurements written inside the shape. In a braille transcription, labels should be placed outside the shape when possible (BANA, 2010). There was tremendous variability in the locations in which participants placed the braille labels. Slightly more than one-third ($n = 46$; 37.4%) of the labels were placed inside the shape. Forty-three (35.0%) labels were placed outside the shape, and it was clear to which angles they were corresponding. On 17 (13.8%) of the graphics, some labels were placed inside the shape and others were placed outside the shape, and it was clear with which angles the labels corresponded. On 15 (12.2%) of the graphics, participants placed the information contained in the labels in other locations such as a key or a transcriber's note. Although rare, sometimes labels were placed outside of shapes and it was not clear to which angles they were corresponding ($n = 2$; 1.6%).

### Transcribers' notes

A transcriber's note provides important information to a tactual reader about special formatting and what has been modified in the braille transcription (BANA, 2011). One in five ($n = 22$; 20.5%) of the worksheets prepared by the participants contained at least one transcriber's note. When used, in 99.3% of the instances the transcribers' notes did not have errors within the text; however, participants transcribed the opening and closing transcriber's note symbol correctly only 57.9% of the time. The primary purpose of transcribers' notes was to inform braille readers where material, especially tactile graphics, are located. A few transcribers' notes explained what symbols were used in the transcription. For example, one transcriber's note on the third-grade worksheet read, "In the picture below, full cells are substituted for ice cream cones." There was variability in where participants placed the transcribers' notes, and some of them on the first-grade worksheet seemed to use above-grade-level vocabulary and sentence structure. For example, one transcriber's note was worded: "Use the attached sheet of braille paper with the tactile path to record your answers by writing them in the numbered boxes. Your answer for problem 1 should begin in box number 1."

## Discussion

When one considers the volume of print material a student must access, it is apparent that individuals preparing those materials for a braille reader must be able to quickly assess what is needed and complete the transcriptions. It was not surprising that the majority of participants spent less than 30 minutes in completing the transcription and used braille translation software to prepare them. Although more than 90% of participants reported that they visually proofread their transcriptions, the majority of the worksheets contained errors, such as misconfigured numbers, headings not centered, and the omission of words and mathematics problems.

The 59 participants who prepared the 107 worksheets volunteered to participate, so it is probable that these individuals had stronger skills in Nemeth code and tactile graphics production than the general population of individuals who prepare mathematics and science worksheets for braille readers. Overall, participants in this study had high levels of accuracy in their production of literary elements and to a somewhat lesser extent Nemeth elements and elements that combined the literary and Nemeth codes.

More participants (10 NLS certified and 22 non-NLS certified) submitted a first-grade worksheet than the other worksheets. Surprisingly, the highest mean error rate in Nemeth occurred on the first-grade worksheet. Some of the errors such as the omission of one or more problems and misconfigured numbers might have caused confusion for young students. It is possible that the simplicity of the mathematics elements on the first-grade worksheet increased the confidence of those who were not NLS certified, in particular teachers of students with visual impairments, to undertake its transcription as opposed to the worksheets that included more advanced mathematics elements. It is also possible that the participants who were not NLS certified, in particular teachers of students with visual impairments, routinely transcribe materials for young students and thus selected the first-grade worksheet.

There was even more variability in formatting across the transcriptions. Participants understood the need to follow the capitalization in headings, to leave a blank line above and below headings, and to begin numbered problems in cell 1. On the other hand, there was less consistency in centering of worksheet titles, placement of directions, and placement of runover lines in mathematics problems. These inconsistencies could potentially affect students' speed and ease of scanning the worksheet for key information.

According to BANA (2010), tactile graphics are essential components of materials transcribed in educational settings. Participants included graphics containing critical information on all but seven of the transcriptions. However, there were errors in the labels of tactile graphics on more than one-third of the transcriptions. There was also variation in the production and placement of the tactile graphics on the page as well as in the use and formatting of transcribers' notes. It was hypothesized that these inconsistencies, along with the formatting and label errors, could affect the ease of scanning and reading for tactile readers. In addition, students who are learning new or difficult mathematics concepts cannot be expected to learn as easily from materials that contain a substantial number of errors or omissions.

There was not a significant difference in the accuracy of Nemeth elements according to job role or primary production method. The only significant difference in the accuracy of Nemeth elements according to certification status was found on the first-grade worksheet. Furthermore, NLS certification status was linked to fewer errors in literary elements and formatting on most of the worksheets. These differences may be explained by the rigorous requirements for literary braille certification of NLS, which include the completion of a correspondence course that comprise a detailed chapter about formatting and the submission of a 35-page manuscript. These measures provide intensive practice in transcribing and proofreading literary materials.

 

Some elements of transcription of mathematics materials seemed to cause more difficulty for many of the participants, regardless of certification or job role. In particular, many of the participants were not certain when to use an English letter indicator. There were often errors in the use of the English letter indicator when labeling the vertex of a shape with a capitalized or lowercase letter, when labeling of the x- and y-axis, and when transcribing abbreviations such as F for Fahrenheit. Although these errors did not occur as often, some participants were not certain when to use or not use the numeric indicator when labeling graphics such as a thermometer or the length of a side of a shape. Additionally, as previously mentioned, some participants were not certain how to format headings, directions, and runover lines of problems.

### Limitations

The study had several limitations. The five worksheets used in the study were not fully representative of the mathematics materials individuals in K-12 settings transcribe. The worksheets did not include any problems that had fractions or exponents, two elements that often are part of the K-12 mathematics curriculum. Formal guidelines for the production of tactile graphics were published at approximately the same time that participants were transcribing the worksheets. It is possible that the guidelines, which are much more extensive than what was previously available, may have been different from the previous training participants received. Another limitation is the fact that the individuals providing the transcriptions were volunteers and may or may not be representative of all individuals creating transcriptions for students who read braille. It is possible that these volunteers might have stronger skills than many others or that they were especially careful with these transcriptions, since they knew their transcriptions would be evaluated. In addition, a higher percentage of participants were NLS certified, so the results might not be representative of the larger sample from the first part of the study. Both authors are primary print readers and read braille visually. Evaluation of the worksheets by tactile readers would have also allowed us to determine tactual readability of the graphics produced by the participants.

### Implications for practitioners

This study provides a beginning body of evidence of the variability in the transcription of mathematics materials for K-12 braille readers. Future studies are needed in which tactile readers are asked to give input about the quality of materials they receive for mathematics and other subjects. In-depth interviews and observations of those preparing braille materials for K-12 students would also be beneficial. In addition to knowing the literary and Nemeth codes, individuals who prepare mathematics materials must be well versed in using braille translation software, guidelines for producing tactile graphics, principles for formatting, and proofreading techniques. More attention needs to be paid to the correct way to format and transcribe mathematics materials during training and throughout the transcription process to avoid making the types of errors that occurred in the transcriptions. Since NLS-certified individuals in this study were more accurate in their formatting and literary braille, it may be beneficial to encourage individuals who prepare materials to become certified. It appears that some individuals preparing braille mathematics materials would benefit from additional support in the form of initial and ongoing professional development related to the production of tactile graphics and principles of formatting, as well as the skills needed to produce mathematics materials using translation programs and to proofread those translated documents. Professional development in the United States should also address how the implementation of Unified English Braille in 2016 will affect the transcription of mathematics materials.

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