Journal of Experimental Child Psychology 209 (2021) 105143

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

The influence of sensory processing tools on attention and arithmetic performance in Dutch primary school children

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ARTICLE INFO

Article history:
Received 16 June 2020
Revised 12 January 2021

Keywords:
Sensory processing
Children
Attention
Arithmetic
Sensory processing tools
Primary school

ABSTRACT

Behavior caused by nonoptimal sensory processing possibly affects school performance. Sensory processing is the ability of the nervous system to process and modulate sensory input and to give an appropriate response. Children with nonoptimal sensory processing are sometimes given tools that are expected to help them concentrate better and achieve better school performance. However, whether these tools are effective and whether the effects depend on children's sensory processing are unknown. To investigate this, a randomized controlled trial was executed. Children attending Grade 2 (N = 271) performed a sustained attention test (the Bourdon–Vos test) and an arithmetic test once a week 4 weeks in a row with a different sensory processing tool every session: tangle, wobble cushion, earmuffs, or nothing (control condition). Sensory processing was assessed with the Sensory Profile NL. To test the effects of sensory processing tools on the Bourdon–Vos and arithmetic test performance, mixed-model analyses were executed. Negative effects of the use of the tangle, earmuffs, and wobble cushion on the Bourdon–Vos total, the use of the tangle and wobble cushion on the Bourdon–Vos correct, and the use of the tangle on the arithmetic test were shown. When children's sensory processing pattern was considered, a negative effect of the use of all tools was shown on the Bourdon–Vos correct for children who already received an optimal amount of stimuli. Considering these

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https://doi.org/10.1016/j.jecp.2021.105143
0022-0965/

results, more research is needed to investigate the effect of longer-term personalized sensory processing tool use on attention and arithmetic performance of children.

Introduction

In every classroom, there are children who have trouble in focusing. They cannot sit still, their thoughts are wandering off, and they are shielding themselves from others or can explode in anger. These behaviors could be caused by nonoptimal sensory information processing and could possibly affect school performance (Ben-Sasson, Carter, & Briggs-Gowan, 2009). Children with nonoptimal sensory information processing are often given sensory processing tools to use during school tasks. It is suggested that by supporting the regulation of the amount of sensory stimuli, children's attention—and, with that, school performance—will improve. However, there is limited research in which the effects of sensory processing tools on attention and school performance in typically developing primary school children have been investigated. In addition, to our knowledge, there are no studies in which the sensory processing of children has been taken into account when investigating the effects of sensory processing tools on attention or school performance. Therefore, the aim of the current study was to investigate the effect of three commonly used sensory processing tools—tangle, earmuffs, and wobble cushion—on attention and arithmetic performance.

Sensory processing

Sensory processing is the ability of the nervous system to process and modulate sensory input and to give the appropriate response to the specific situation at hand. Sensory input, also called stimuli, is perceived by the body via the senses and is then processed by the central nervous system. For the modulation of sensory input, two neuropsychological processes are important: habituation and sensitization (Dunn, 1997). Habituation is the process in which the central nervous system recognizes a stimulus as familiar and nonimportant and the need to respond to this stimulus is discontinued (e.g., not responding to the constant ticking of a clock). Sensitization is the opposite process in which a stimulus is recognized as important and/or dangerous and a heightened response is generated (e.g., whether children react when a teacher calls their name). The central nervous system continuously needs to switch between habituation and sensitization to produce optimal functional behavior. The balance between habituation and sensitization is different for every person depending on one's experiences and genetics; this balance is expressed in a threshold (Dunn, 1997). This threshold is a continuum and can vary from low (i.e., a person needs very few or weak stimuli to react) to high (i.e., a person needs many or very strong stimuli to react). The hypothesized thresholds are in accordance with the Yerkes–Dodson law of optimal arousal, which indicates that an optimal amount or intensity of sensory stimuli is needed to achieve the optimal level of arousal to accomplish the best performance on tasks (Wekselblatt & Niell, 2015). To achieve this optimal level of arousal, some people need a small amount of stimuli (i.e., low threshold), whereas others need a large amount of stimuli (i.e., high threshold).

Some people actively regulate the amount of experienced stimuli by adding stimuli if their threshold is not reached or by removing stimuli if their threshold is violated; this is the behavioral strategy of sensory processing. This behavioral strategy is a continuum and can range from passive (i.e., the person does nothing to protect or reach his or her threshold) to active (i.e., the person actively protects his or her threshold and will try to either meet a high threshold or avoid violating a low threshold). According to Dunn (1997), these two aspects (i.e., threshold and behavioral strategy) can be combined into four sensory processing patterns: registration (i.e., high threshold, passive strategy), sensitivity (i.e., low threshold, passive strategy), seeking (i.e., high threshold, active strategy), and avoiding (i.e., low threshold, active strategy).

A lot of research with regard to sensory processing has been executed in children with attention-deficit/hyperactivity disorder (ADHD) or autism spectrum disorder (ASD) (Dunn & Bennett, 2002; Ghanizadeh, 2011; Marco, Hinkley, Hill, & Nagarajan, 2011; van der Linde, Franzsen, & Barnard-Ashton, 2013). Behavioral expressions commonly reported to occur in children with ADHD or ASD can be explained partly by sensory processing problems (Ben-Saddon, Hen et al., 2009; Ghanizadeh, 2011). However, there are also indications that nonoptimal sensory processing—and, with that, attention problems—also occur in children without behavioral diagnoses (Little, Dean, Tomchek, & Dunn, 2017).

Sensory processing and attention/learning performance

It has been suggested that optimal sensory processing is the basis for developing academic skills, among others (Ben-Sasson, Carter, et al., 2009). However, whether nonoptimal sensory processing is related to attention and school performance in typically developing children has not been studied extensively yet. There are two earlier studies in which the relationship between sensory processing and school performance was investigated. In these studies, both typically developing children and children with fetal alcohol spectrum disorder (Jirikowic, Olson, & Kartin, 2008) and learning disorders (Parham, 1998) were included. In both studies, a significant positive correlation between sensory processing and reading and math (Parham, 1998) and spelling and math (Jirikowic et al., 2008) was shown.

Tools

In primary schools, tools to support sensory processing (here called sensory processing tools) are frequently used. Earmuffs, wobble cushions, and tangles are used because occupational therapists suggest that they improve the attention of children with nonoptimal sensory processing by either removing sensory stimuli (earmuffs) or adding sensory stimuli (tangle and wobble cushion) in a nonintrusive way. The suggestion is that these sensory processing tools remove or add stimuli to achieve the threshold of children and, with that, an optimal level of arousal that causes optimal attention necessary for the most favorable performance on school tasks.

There is a vast array of sensory processing tools available such as chewing toys, fidget toys, and pressure vests. In a number of earlier studies, the effects of sensory processing tools in typically developing primary school children on behavior (Fedewa & Erwin, 2011; Gaston, Moore, & Butler, 2016; Pfeiffer, Henry, Miller, & Witherell, 2008; Rollo, Crutchlow, Nagpal, Sui, & Prapavessis, 2019; Wekselblatt & Niell, 2015), writing (Stalvey & Brasell, 2006), and reading comprehension (Smith & Riccomini, 2013) were investigated. Three sensory processing tools that are commonly used in Dutch primary schools are the tangle, earmuffs, and the wobble cushion.

As far as we are aware, no previous studies have used a tangle (i.e., a kind of fidget toy) in typically developing children, but others have investigated the effects of other fidget toys such as fidget spinners (i.e., devices that can be held between the fingers and rotated) and stress balls. It has been suggested that fidgeting can lead to increased concentration by adding stimuli (Schecter, Shah, Fruitman, & Milanaik, 2017). Recent studies showed that university students, who used fidget spinners during the learning phase of their experiment, had lower memory performance than control group members, who used no fidget spinner during the learning phase when remembering the content of a lecture (Soares & Storm, 2019) or words (Amico & Schaefer, 2020). In the same participants, Amico and Schaefer (2020) also showed that the use of a stress ball did not lead to improved memory performance compared with using no stress ball. The only study in which a significant positive effect of a fidget toy in typically developing children was shown was that of Stalvey and Brasell (2006). In their study, primary school students could use a stress ball three times per week for 30 min during writing instruction for a total of 7 weeks. There were significantly fewer distractions during the writing instructions when the stress ball was used, and the mean writing score increased. Thus, there is some evidence that fidget toys have a negative effect on memory in the short run and have a positive effect on memory in the long run. However, the fidget spinner is a fidget toy that rotates intensely and makes a sound; this could distract both the child using it and others in the classroom. The tangle does not move extensively and does not make a sound and hence is probably less distracting. Therefore, its use might be more likely to lead to positive effects on attention and arithmetic test performance.

There are many studies investigating the effect of "dynamic seating" on a vast array of measurements (for a review, see Rollo et al., 2019). There are many forms of dynamic seating such as stability balls, wobble cushions, therapy ball chairs, and even standing or cycling desks. It has been suggested that dynamic seating tools can improve sensory processing by providing more proprioceptive and vestibular sensory input than normal chairs and that by improving the sensory processing, the ability to learn would be improved (Pfeiffer et al., 2008; Rollo et al., 2019). Many of the studies in which the effects of dynamic seating are investigated focus on children with ADHD or ASD, focus on behavior-oriented outcome measures such as in-seat behavior and on-task behavior, or investigate attention via a questionnaire filled out by the teacher (Fedewa & Erwin, 2011; Gaston et al., 2016; Pfeiffer et al., 2008; Rollo et al., 2019; Wekselblatt & Niell, 2015). In their review, Rollo et al. (2019) concluded that classroom-based dynamic seating could be an effective strategy to improve teacher-reported attention, but not academic performance, among typically developing children. Thus, there seems to be some evidence that dynamic seating could lead to improved attention measured with questionnaires filled out by teachers; however, whether this is also the case when using an objective measure of attention is uncertain.

Very few studies have investigated the effects of earmuffs on attention or school performance in typically developing children. Earmuffs are thought to be effective for children with low thresholds, for whom it might be beneficial to remove/reduce auditory stimuli. Smith and Riccomini (2013) investigated 254 elementary school children (Grades 3–5) with and without (learning) disabilities who executed a reading comprehension test while using earmuffs or no earmuffs. They showed that for typically developing children, there was no significant difference between the two conditions. For children with learning disabilities, the mean reading comprehension score improved when the earmuffs were used, but this improvement was not significant. For children with other disabilities (e.g., speech and language impairment), the improvement with earmuffs was significant, but this group was very small (n = 17). Thus, this indicates a nonsignificant effect of earmuffs on reading comprehension in typically developing children; however, whether this is also the case for attention and arithmetic is unknown.

Differential effects of sensory processing tools for different sensory processing patterns

In none of the studies mentioned above, where the effect of sensory processing tools was investigated, was sensory processing taken into account, whereas an effect of sensory processing tools is expected to be dependent on the sensory processing of children. Thus, the goal of the current study was to investigate whether the use of sensory processing tools has an acute effect on attention and arithmetic test performance and, if so, whether the effects are differential for the categories "less than others," "similar to others," and "more than others" on each of the sensory processing patterns (registration, sensitivity, seeking, and avoiding). The tangle and wobble cushion were expected to be effective for children with a high threshold (i.e., those who show behavior more than others on the sensory processing patterns *registration* and *seeking*). The earmuffs were expected to be effective for children with a low threshold (i.e., those who show behavior more than others on the sensory processing patterns *sensitivity* and *avoiding*).

Method

Participants

All children attending second grade (i.e., in Dutch *groep 4*) at the participating schools were eligible to participate. The choice of children in second grade was pragmatic. It has been suggested that nonoptimal sensory processing decreases with age (Cheung & Siu, 2009); therefore, we chose to include children aged 7 and 8 years. In the Netherlands, structured learning is introduced in Grade 1. We choose to include children attending Grade 2 because they are used to the structured learning and are able to perform sustained attention and arithmetic tests in a reliable way. There were no exclusion criteria because the goal was to achieve a representative sample of the general primary school population.

Study design

The current study was a randomized controlled trial. All children executed a sustained attention test and an arithmetic test using a tangle, a wobble cushion, earmuffs, or no sensory processing tool (control condition) (see Fig. 1). Children performed the attention test and the arithmetic test once a week 4 weeks in a row. During each testing session, children received a different sensory processing tool. The order in which children used the sensory processing tools was randomized. The study was approved by the ethical committee of the Open University (U2018/06659/SVW) and was registered at the Netherlands Trial registry (NTR7453).

Procedure

Primary schools in the south of the Netherlands were contacted to participate in the current study. Eventually, nine school boards gave approval to participate in the study. All children attending second grade (aged ~7–8 years) at the participating schools were given an information letter by their teachers. The information letter explained the goal of the study, and the children were asked to hand this information letter over to their parents. The information letter also contained an informed consent form (for an overview of the study, see Fig. 1). In addition, the information letter and informed consent were put on the school electronic message system. The information letter contained contact information of the researchers so that parents could contact the researchers if they had questions. Parents were asked to fill out the informed consent, indicate whether their child was allowed to participate in the study (yes or no), and hand in the signed informed consent form to the teacher of their child. The teacher sent out a reminder to parents after 1 week.

After 2 weeks, informed consents were collected and children for whom informed consent was received participated in a practice session. In this practice session, children used all the sensory processing tools for approximately 10 min per tool. After the practice session, children received an envelope with the Dutch version of the Sensory Profile (SP-NL) and some additional background questions that parents were asked to fill out and return in a closed envelope to the teacher. The week after the practice session, the repeated measures started and children executed a sustained attention test and an arithmetic test every week for 4 weeks while using one of the three sensory processing tools or no sensory processing tool (control condition; randomized over participants and test sessions). Immediately after the last test session, children filled out a questionnaire regarding their opinion of the sensory processing tools that they had used during the test sessions. Recruitment and data collection took place from October to December 2018.

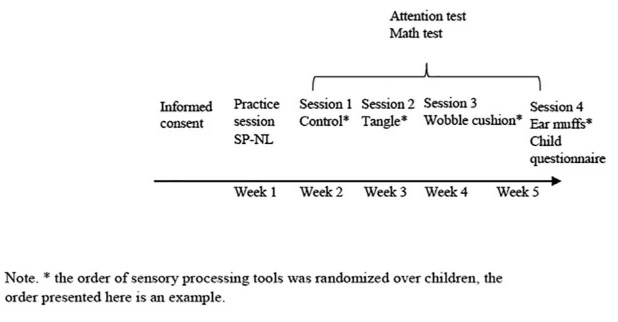

Fig. 1. Overview of the study.

Sensory processing tools

In the current study, sensory processing tools that add stimuli for children with a high threshold (i.e., tangle and wobble cushion) and sensory processing tools that remove stimuli for children with a low threshold (i.e., earmuffs) were included. These sensory processing tools were selected based on a number of pragmatic reasons, namely that they are commonly used in primary schools, they are relatively cheap (all <40 euros), and they are not a nuisance to other students and/or the teacher.

The tangle is a fidget toy and consists of a multitude of small plastic arches that can be moved independently. For the current study, the Tangle Classic Junior, a smooth-surface tangle, was used. A wobble cushion is a round air-filled cushion that can be placed on a normal chair. A wobble cushion allows a child to move around without irritating other students or the teacher. In the current study, the Togu Dynair for Kids wobble cushion with a diameter of 15 cm was used. Earmuffs look like music headphones; however, due to the padded ear pads, earmuffs reduce sound levels. In the current study, the 3 M PELTOR Optime II was used; these earmuffs are able to reduce sound levels by 31 decibels (a normal conversation is ~60 decibels).

Data collection

Sensory processing

To assess sensory processing and the sensory processing patterns, we used the SP-NL (Dunn & Rietman, 2013). The SP-NL consists of 125 questions and is filled out by the parents and/or caregivers. The questions are related to sensory processing behavior that children can show. Parents rate how often their child shows a specific behavior on a 5-point Likert scale (1 = *always* [100% of the time], 2 = *frequently* [>75% of the time], 3 = *occasionally* [25–75% of the time], 4 = *seldom* [<25% of the time], 5 = *never* [0% of the time]). Based on the questionnaire, scores for the four sensory processing patterns (registration, sensitivity, seeking, and avoiding) were calculated. Note that there are specific questions for each sensory processing pattern. The scores per sensory processing pattern were then converted into the categories "less than others," "similar to others," and "more than others." These categories are based on the scores on the SP-NL of a group of 1257 typically developing Dutch children in the same age range (6–10 years) (Dunn & Rietman, 2013). "Less than others" is a score of more than 1 standard deviation (SD) below the average score for a specific sensory processing pattern (i.e., 15.9% of children), "similar to others" is a score between 1 SD below and 1 SD above the average for a specific sensory processing pattern (i.e., 68% of children), and "more than others" is a score more than 1 SD above the average (i.e., 15.9% of children) for a specific sensory processing pattern. The internal consistency of the SP-NL sensory processing patterns is good (all Cronbach's alphas > .81) (Dunn & Rietman, 2013). The item rest correlation (i.e., the correlation between one question and the other questions of the sensory processing pattern) is in general good; all items had a correlation > .30 with the exception of one item on the sensory processing pattern *sensitivity* that was just below the threshold (.17; threshold is > .20) (Dunn & Rietman, 2013). The original Sensory Profile questionnaire has been shown to have high test–retest reliability and internal consistency (Ohl et al., 2012) and is able to differentiate among children diagnosed with ASD, children diagnosed with ADHD, and typically developing children (Ermer & Dunn, 1998; Reynolds & Lane, 2008), and the convergent validity is moderate (Brown, Morrison, & Stagnitti, 2010).

Attention measure

To measure attention, the Bourdon–Vos test was used (Vos, 1998). The Bourdon–Vos test is a time-limited paper-and-pencil test that measures sustained selective attention. The test consists of 33 lines with 24 stimuli per line. On every line, there are figures consisting of three, four, or five dots. Children are asked to strike out the four-dot figures (i.e., target stimuli) as quickly and accurately as possible while ignoring the three- and five-dot figures (i.e., distractor stimuli) within a given time limit. The test can be administered both individually and in a classroom setting. In the current study, the test was administered in a classroom setting, and children were given 8 min to process as many stimuli as possible. The time limit of 8 min was based on a formula provided in the manual. It is suggested to take a hypothetical time in which it is impossible to finish one line. We based this hypothetical time on the average time it took a 7-year-old child from the reference population to finish one line as mentioned in the Bourdon–Vos test manual. This is 20.9 s (*SD* = 3.2). We subtracted the SD from the average for one line (20.9–3.2 = 17.7 s) and then subtracted 2.5 s (17.7–2.5 = 15.2 s) to achieve the hypothetical unachievable time to finish one line. Then, we multiplied the hypothetical time of 15.2 s per line with the number of lines in the test (*n* = 33), which gave us a hypothetical unachievable time of 8 min 37 s to finish the sheet. Lastly, we rounded down this time to 8 min. The construct validity and reliability of the Bourdon–Vos test are acceptable (Egberink, Leng, & Vermeulen, 1997). The Bourdon–Vos test does not have parallel versions; thus, the same test was used at all four test moments.

During testing, it was noticed that some children finished the whole test sheet within the time limit of 8 min. To prevent a ceiling effect, an additional test sheet, turned around 180 degrees to prevent retest effects, was added. For the data analyses, the total number of stimuli processed (Bourdon–Vos total), the number of target stimuli correctly processed (Bourdon–Vos correct), the total number of target stimuli not crossed out (i.e., error of omission; Bourdon–Vos O ERR), and the total number of nontarget stimuli crossed out (i.e., error of commission; Bourdon–Vos C ERR) per measurement moment were used as measures of attention.

Arithmetic test

To measure arithmetic performance, a self-developed arithmetic test was used. This arithmetic test was developed by one of the authors (C.M.), who has a degree as a primary school teacher, in cooperation with other educational professionals. The test was a tempo-based arithmetic test, which is a common way in which the arithmetic abilities of children are tested in the Dutch educational system, so the children were used to this way of testing. In a tempo arithmetic test, children get a sheet with arithmetic problems and need to solve as many problems as possible within a certain time limit. The arithmetic test used in the current study consisted of two sheets, each with four rows of seven columns consisting of 5 arithmetic problems, for a total of 280 arithmetic problems. Rows of additions and subtractions were alternated, and the difficulty of the arithmetic problems increased. The first sheet contained only arithmetic problems with solutions under the number 10 (e.g., 4 + 5 but not 4 + 7). On the second sheet, the arithmetic problems on the upper half of the page were calculations with solutions up to the number 20 without exceeding 10 within the calculation (e.g., 12 + 5 but not 7 + 5), and the lower half of the second page contained arithmetic problems up to 20 with exceeding 10 within the calculation (e.g., 7 + 5). Children were given 8 min to solve as many arithmetic problems as possible in the order specified by the researcher (first the whole row of blocks of additions, then the whole row of blocks of subtractions, etc.).

There were four parallel versions of the arithmetic test, with the same arithmetic problems in differing order while keeping the increasing difficulty intact. The arithmetic tests were presented in such a way that all participants received all four arithmetic tests but in a randomized order. For the data analyses, the total number of correctly filled out arithmetic problems per measurement moment was used.

Other measurements

Information about the sex of the child and birth date of the child was collected on the SP-NL and the informed consent, respectively.

Data processing

All Bourdon–Vos and arithmetic tests were scored by two researchers, with any discrepancies being resolved by discussion. After checking, all results were entered twice in a database; the databases were checked for any discrepancies among the data entries, and these discrepancies were resolved. For the SP-NL, the same procedure was followed. Then, sensory processing pattern scores and categories within the sensory processing patterns were calculated. Some parents forgot to fill out questions or crossed out multiple answer options. When parents forgot to fill out or wrongly filled out one question for a sensory processing pattern, it was checked whether the score of that specific question could change the category (i.e., "less than others," "similar to others," or "more than others") by using a score of 1 (minimum) and a score of 5 (maximum). If this value replacement did not change the category, that category was used; if the category changed, the category was left empty and was not used in the data analyses.

Sample size calculation

The original sample size calculation was based on a repeated-measures analysis of variance (ANOVA). With a small effect size of f = .10 and an alpha of .05, 216 participants were sufficient for a power of .80. A conservative effect size was chosen because at the time the study was designed, no previous studies in which the effects of the sensory processing tools used in the current study were studied on the performance of typically developing primary school children were known. After careful consideration, it was decided that mixed-model analysis was a more suitable statistical analysis method for the current study. To calculate the power for the interaction effect (i.e., the only effect with a hypothesis), we used a simulation approach.

There are no earlier studies investigating the interaction between sensory processing tools and sensory processing profile on attention. Therefore, we based the needed expected effect (i.e., number of extra stimuli processed on the Bourdon–Vos test) for the power calculation on the increase of children's ability to process stimuli with age (i.e., to become faster). Children aged 7 years need on average 20.9 s to process 1 line of the Bourdon–Vos test (i.e., 24 stimuli), and children aged 8 years need on average 18.1 s per line. Thus, there is a decrease in time needed to complete the original test of 2.8 s per line (20.9–18.1 s) and a total of 92.4 s for the whole test (2.8 s × 33 lines). We took a hypothetical increase of half a year as a clinical relevant outcome; that is, children would complete the original test 46.2 s faster (92.4 s × 0.5). Given the average time to finish 1 line of stimuli of a 7-year-old child (20.9 s for 24 stimuli), a child would be able to process 53 stimuli within those 46.2 s [(46.2 s/20.9 s) × 24 stimuli per line]; thus, we took 53 stimuli as the hypothesized effect size for the sample size calculation.

Based on this expected small interaction effect, we simulated 1000 datasets using the R packages *simr* (Green & MacLeod, 2016) and *emmeans* (Lenth et al., 2020). Specifically, the interaction we expected was that only the category "more than others" on the sensory processing patterns *sensitivity* and *avoiding* in the earmuffs condition differed from other categories/learning tools by 53 points. In addition, we expected that the category "more than others" on the sensory processing patterns *registration* and *seeking* in the tangle and wobble cushion conditions would differ from the other categories/learning tools. Variance of random intercepts and residual variance used in the simulations were based on the actual data. With a sample size of 357, the simulations showed for 804 of 1000 analyses that adding the interaction to the data analysis led to a significant improvement of the model; hence, with N = 357, a power higher than 80% was attained.

Note that all children of a class were invited to participate, not individual children. Therefore, a sample size of 271 participants was achieved.

Statistical analyses

To check whether the four versions of the arithmetic test were parallel, an ANOVA was executed with the total number of correctly filled out arithmetic problems as outcome measure and the arithmetic test version as factor. The ANOVAs were executed in SPSS Version 24.

To test the effects of sensory processing tools on the Bourdon–Vos and arithmetic test performance, mixed-model analyses were executed. Originally, it was planned to execute a repeated-measures ANOVA; however, new insight indicated that mixed-model analyses would give more reliable results because this analysis takes the variance within a participant into account. Thus, analyses were conducted using linear mixed models that accounted for repeated measurements in participants. These analyses were executed in the R statistical environment (R Studio Version 3.3.2) with the package *nlme* Version 3.1–131 using the standard settings for all analyses except for the analysis for the crossed out nontarget stimuli (Pinheiro, Bates, DebRoy, & Sarkar, 2007). Because the Bourdon–Vos C ERR had a skewed distribution, the generalized linear mixed-effects (Poisson) model option and the bootstrapping method were used to determine the 95% confidence interval (CI) in the package *lme4* (Bates, Mächler, Bolker, & Walker, 2015).

First, it was checked whether mixed-model analyses were necessary; this was done by comparing the −2 log likelihood (−2LL) of a model with a fixed intercept only to the −2LL of a model with a random intercept only. After these two analyses, models were built in a stepwise way. One variable was added, and the new model was compared with the previous model. If the change in −2LL indicated a significant improvement of the model, the variable was kept in the model. The addition of variables was done in the following order: (1) test moment, (2) random slope for test moment, (3) quadratic term for test moment (test moment^2), (4) sex, (5) sensory processing tool, (6) sensory processing pattern, (7) interaction sensory processing pattern × sensory processing tool. Separate models were built for each outcome measure (i.e., Bourdon–Vos total, Bourdon–Vos correct, Bourdon–Vos O ERR, Bourdon–Vos C ERR, and arithmetic test).

In addition, subgroup analyses investigating the effect of the sensory processing tool use on all outcome measures were performed separately for the categories ("less than others," "similar to others," and "more than others") of the sensory processing patterns.

Due to the longitudinal nature of the current study, not all participants had data available for all measurement moments, but all participants who were present at one or more measurement moments were included in the analyses. Missing data were not imputed, which is valid under the same missingness assumptions as multiple imputation (Verbeke & Molenberghs, 2009), and $p < .05$ was considered to be statistically significant.

Results

A total of 271 children were included in the study. Information about sex was available for 257 participants (inquired via the SP-NL); there were 132 boys and 125 girls. Information about age was available for 264 children (inquired via informed consent); the average age of these children was 7.58 years ($SD = 0.43$).

Sensory profile patterns

A total of 257 parents returned the SP-NL questionnaire. Unfortunately, some of these parents did not fill out certain questions or filled out multiple answers for one question, so not all children's scores on all sensory processing patterns are available; a total of 229 children had a score available for all sensory processing patterns (missing scores: registration $n = 3$, seeking $n = 17$, sensitivity $n = 10$, avoiding $n = 9$). The majority of children were classified in the "similar to others" category for all sensory processing patterns (63.7–70.9%; see Table 1). However, 12–16.9% of children were classified in the "less than others" category and 17.1–19.4% of children were classified in the "more than others" category for the four sensory processing patterns (see Table 1).

Data checking

A total of 69 children executed two test sessions with just one sheet of the Bourdon–Vos test; all other children executed all test sessions with two sheets (see Method). In case a child had finished the whole first sheet of the Bourdon–Vos test and had not received the second sheet, the data for the test moment was excluded from the analyses ($n = 15$), because the finished sheet might be an underestimation of the child's actual performance (i.e., he or she could have achieved a higher score). Note that data on the other test moments were included for these participants. In addition, 10 Bourdon–Vos tests could not be scored because the tests were not executed according to instructions (e.g., stimuli were crossed out vertically instead of horizontally), and 9 arithmetic tests could not be included because the tests were not executed according to instructions (e.g., participants filled out only additions and not subtractions). Moreover, 18 children were not present at one test session and 4 participants were not present at two test sessions. This resulted in 1033 total valid measurements for the Bourdon–Vos test and 1049 valid measurements for the arithmetic test. When taking valid sensory

Table 1
Frequency of sensory profile pattern categories.

	Less than others [n (%)]	Similar to others [n (%)]	More than others [n (%)]	Total (N)
Registration	30 (12.0%)	178 (70.9%)	43 (17.1%)	251
Seeking	40 (16.9%)	151 (63.7%)	46 (19.4%)	237
Sensitivity	36 (14.8%)	162 (66.4%)	46 (18.9%)	244
Avoiding	40 (16.3%)	162 (66.1%)	43 (17.6%)	245

processing pattern data into account, 965, 910, 936, and 942 data points for *registration, seeking, sensitivity,* and *avoiding,* respectively, were available for the Bourdon–Vos test. For the arithmetic test, there were 978, 923, 951, and 955 data points available for *registration, seeking, sensitivity,* and *avoiding,* respectively.

We checked whether there were differences in the performance on the four versions of the arithmetic test. There was no significant difference between the arithmetic tests, $F(3, 1045) = 0.186$, $p = .906$, indicating that the four versions were statistically parallel.

Effects of sensory processing tools without taking sensory processing pattern category into account

When comparing the mixed models for the effects of sensory processing tools on the performance on the Bourdon–Vos test, the model with test moment, test moment^2, and sensory processing tool was the best model for both the Bourdon–Vos total and correct measures. For both the Bourdon–Vos O ERR and C ERR, the best model did not contain the sensory processing tool; therefore, we do not report further on these measures.

For both the Bourdon–Vos total and correct measures, there was a clear learning effect given that test moment was significant (see Table 2). Moreover, the test moment squared showed that for both Bourdon–Vos measures the increase in performance was not linear over test moment but that the learning effect was attenuated over time. The use of all three sensory processing tools had significant negative effects on the Bourdon–Vos total as compared with the control condition without a sensory processing tool (see Table 2). For the Bourdon–Vos correct, there were significant negative effects of the tangle and wobble cushion, but not of the earmuffs, compared with the control condition without a sensory processing tool (see Table 2).

When comparing models looking at the effects of sensory processing tools on arithmetic test score, the best model contained test moment and sensory processing tool. Thus, there was a learning effect for the arithmetic test given that test moment was significant. Test moment squared was not significant, which indicates a linear learning effect. When investigating the effects of sensory processing tools on the arithmetic test, there was a significant negative effect of the tangle but no significant effects of the earmuffs or wobble cushion as compared with the control condition without a sensory processing tool (see Table 2).

Effect of sensory processing tools while taking sensory processing pattern category into account

When comparing models looking at the effects of sensory processing tools on the Bourdon–Vos scores while taking sensory processing pattern category into account, the best fitting model for both Bourdon-Vos measures, for *seeking*, *avoiding* and *sensitive*, and for Bourdon-Vos total score for *registration* was the model with the addition of the sensory processing pattern category).

The addition of sensory processing pattern categories to the model showed that there were significant differences in the scores on the Bourdon–Vos test scores between the sensory processing pattern categories. Children who showed behavior "more than others" on the sensory processing patterns *registration, avoiding,* and *sensitivity* had significantly lower scores on both Bourdon–Vos measures than children who showed behavior "similar to others" (see Table 3).

Table 2
Results of mixed-model analyses effect of sensory processing tools on Bourdon–Vos and arithmetic test scores without taking the sensory processing pattern category into account.

	B	*SE b*	95% Confidence interval
BV total			
Intercept	413.19	13.52	**[386.72, 439.66]**
Test moment	136.17	9.92	**[116.76, 155.58]**
Test moment^2	−16.44	1.89	**[−20.13, −12.74]**
Tangle[a]	−30.16	5.97	**[−41.85, −18.47]**
Earmuffs[a]	−14.58	5.92	**[−26.18, −2.99]**
Wobble cushion[a]	−23.80	6.07	**[−35.68, −11.92]**
BV correct			
Intercept	124.62	4.33	**[116.14, 133.09]**
Test moment	50.03	3.16	**[43.85, 56.21]**
Test moment^2	−6.29	0.60	**[−7.47, −5.11]**
Tangle[a]	−9.07	1.90	**[−12.80, −5.35]**
Earmuffs[a]	−3.30	1.89	[−6.99, 0.40]
Wobble cushion[a]	−6.31	1.93	**[−10.09, −2.53]**
Arithmetic test			
Intercept	92.95	3.04	**[86.99, 98.91]**
Test moment	2.52	0.57	**[1.41, 3.63]**
Test moment^2	–	–	–
Tangle[a]	−2.82	1.40	**[−5.55, −0.08]**
Earmuffs[a]	1.00	1.40	[−1.74, 3.74]
Wobble cushion[a]	0.52	1.41	[−2.25, 3.28]

Note. Significant 95% confidence intervals are in bold. BV, Bourdon–Vos. Mixed models with random intercept for participants and random slope for test moment are shown.
[a] Control condition as reference.

The addition of the interaction term sensory processing pattern category × sensory processing tool improved the model significantly only for the sensory processing pattern *registration* for the Bourdon–Vos correct score (see Table 3) (for all analyses, see Supplementary Table S1 in the online supplementary material). For this analysis, we executed subgroup analyses; thus, separate analyses were conducted for the categories "less than others," "similar to others," and "more than others" in which the Bourdon–Vos correct scores were compared between the tools and control conditions (see Table 5 and Fig. 2) (for all subgroup analyses, see Supplementary Table S2). These subgroup analyses showed that children who showed *registration* behavior in an amount "similar to others" performed worse on the Bourdon–Vos correct measure with all three sensory processing tools compared with the control condition. For children who showed *registration* behavior "more than others" or "less than others," the use of the sensory processing tools did not have a significant effect on the Bourdon–Vos correct score compared with the control condition.

When comparing models looking at the effects of sensory processing tools on the arithmetic test scores while taking sensory processing pattern category into account, the best-fitting model for the sensory processing patterns *seeking* and *sensitivity* was the model with the addition of the sensory processing pattern category (see Table 4). For the sensory processing patterns *avoiding* and *registration*, the model did not significantly improve when sensory processing patterns category was added.

The addition of sensory processing pattern categories to the model showed that there were significant differences in the scores on the arithmetic test scores between the sensory processing pattern categories. Children who showed behavior on the sensory processing patterns *seeking* and *sensitivity* "less than others" had significantly more correctly finished arithmetic problems than children who showed behavior "similar to others" (see Table 3).

The addition of the interaction term sensory processing pattern category × sensory processing tool did not improve any of the models (for completeness, the analyses with the interaction term are included in Supplementary Table S1 and the subgroup analyses are included Supplementary Table S2).

Table 3
Results of mixed-model analyses effects of sensory processing tools on Bourdon–Vos and arithmetic test scores while taking sensory processing pattern category into account.

	BV Total			BV Correct			Arithmetic test correct		
	b	SE	95%CI	b	SE	95%CI	b	SE	95%CI
Registration	*-2LL 11626.24, df 12, p =.004°*			*-2LL 9430.319, df 12, p = .003°*			*-2LL 9099.291, df 11, p = .077°*		
Intercept	432.47	14.60	**(403.92; 461.03)**	130.95	4.69	**(121.79; 140.11)**	93.93	3.64	**(86.81;101.06)**
Test moment	135.43	10.20	**(115.49; 155.36)**	49.55	3.25	**(43.20; 55.90)**	2.70	0.59	**(1.55; 3.85)**
Test moment^2	-16.45	1.94	**(-20.24; -12.65)**	-6.26	0.62	**(-7.47; -5.05)**	-	-	-
Tangle•	-32.49	6.11	**(-44.44; -20.55)**	-9.72	1.95	**(-13.53; -5.92)**	-3.06	1.44	**(-5.88; -0.24)**
Earmuffs•	-15.45	6.07	**(-27.33; -3.58)**	-3.54	1.93	(-7.32; 0.24)	1.02	1.44	(-1.79; 3.84)
Wobble cushion•	-22.73	6.23	**(-34.90; -10.55)**	-6.02	1.98	**(-9.90; -2.15)**	0.49	1.46	(-2.36; 3.35)
Registration – less⁂	-5.01	24.80	(-53.66; 43.63)	1.85	8.09	(-14.02; 17.73)	11.60	9.06	(-6.18; 29.38)
Registration - more⁂	-71.36	21.37	**(-113.27; -29.45)**	-23.29	6.97	**(-36.96; -9.62)**	-12.73	7.82	(-28.07; 2.61)
Avoiding	*-2LL 11353.87, df 12, p = .017°*			*-2LL 9208.729, df 12, p = .019°*			*-2LL 8891.276, df 11, p = .070°*		
Intercept	424.44	15.01	**(395.10; 453.79)**	128.89	4.81	**(119.48; 138.29)**	91.24	3.81	(83.79; 98.69)
Test moment	137.26	10.39	**(116.94; 157.57)**	49.88	3.30	**(43.43; 56.33)**	2.66	0.59	(1.50; 3.82)
Test moment^2	-16.92	1.98	**(-20.80; -13.05)**	-6.38	0.63	**(-7.60; -5.14)**	-	-	
Tangle•	-31.95	6.22	**(-44.10; -19.79)**	-9.59	1.97	**(-13.45; -5.73)**	-2.96	1.47	(-5.82; -0.09)
Earmuffs•	-13.98	6.20	**(-26.10; -1.85)**	-3.19	1.97	(-7.03; 0.66)	1.08	1.47	(-1.79; 3.95)
Wobble cushion•	-23.60	6.36	**(-36.03; -11.17)**	-6.30	2.02	**(-10.25; -2.36)**	0.50	1.48	(-2.41; 3.40)
Avoiding – less⁂	15.29	21.95	(-27.76; 58.34)	5.68	7.18	(-8.40; 19.76)	15.89	8.11	(-0.02; 31.80)
Avoiding - more⁂	-54.94	21.32	**(-96.76; -13.12)**	-17.41	6.97	**(-31.09; -3.73)**	-6.31	7.88	(-21.78; 9.16)
Seeking	*-2LL 10993.49, df 12, p = .489°*			*-2LL 8921.111, df 12, p = .229°*			*-2LL 8584.28, df 11, p = .013°*		
Intercept	417.98	15.65	**(387.40; 448.57)**	126.24	5.02	**(116.43; 136.05)**	90.88	3.91	**(83.22; 98.53)**
Test moment	136.73	10.64	**(115.93; 157.53)**	50.19	3.38	**(43.57; 56.81)**	2.90	0.61	**(1.71; 4.09)**
Test moment^2	-16.77	2.03	**(-20.73; -12.81)**	-6.41	0.64	**(-7.67; -5.15)**	-	-	-
Tangle•	-30.12	6.39	**(-42.61; -17.62)**	-9.29	2.03	**(-13.26; -5.32)**	-3.06	1.48	**(-5.97; -0.16)**
Earmuffs•	-14.48	6.37	**(-26.93; -2.04)**	-3.39	2.02	(-7.35; 0.57)	0.47	1.49	(-2.44; 3.37)
Wobble cushion•	-22.67	6.52	**(-35.43; -9.92)**	-6.00	2.07	**(-10.06; -1.95)**	0.48	1.50	(-2.46; 3.42)
Seeking – less⁂	21.17	23.07	(-24.08; 66.42)	10.31	7.52	(-4.44; 25.05)	20.93	8.10	**(5.03; 36.82)**
Seeking - more⁂	-11.88	21.67	(-54.38; 30.63)	-5.00	7.06	(-18.85; 8.84)	-6.55	7.67	(-21.60; 8.51)
Sensitive	*-2LL 11295.7 , df 12, p = 0.006°*			*-2LL 9162.207, df 12, p = .0002°*			*-2LL 9162.207, df 11, p = .004°*		
Intercept	431.25	15.15	**(401.63; 460.86)**	131.16	4.85	**(121.68; 140.65)**	91.88	3.79	**(84.46; 99.30)**
Test moment	135.65	10.43	**(115.25; 156.04)**	49.38	3.31	**(42.90; 55.86)**	2.74	0.60	**(1.57; 3.91)**
Test moment^2	-16.61	1.98	**(-20.49; -12.73)**	-6.27	0.63	**(-7.50; -5.03)**	-	-	-
Tangle•	-30.20	6.27	**(-42.46; -17.94)**	-8.98	1.99	**(-12.87; -5.08)**	-3.35	1.45	**(-6.18; -0.52)**
Earmuffs•	-14.31	6.22	**(-26.47; -2.14)**	-3.12	1.98	(-6.98; 0.74)	0.53	1.45	(-2.30; 3.36)
Wobble cushion•	-23.21	6.39	**(-35.69; -10.72)**	-6.12	2.03	**(-10.09; -2.16)**	0.07	1.46	(-2.80; 2.93)
Sensitive – less⁂	1.53	23.37	(-44.31; 47.37)	2.09	7.62	(-12.86; 17.04)	22.81	8.42	**(6.28; 39.34)**
Sensitive - more⁂	-80.81	21.13	**(-122.26; -39.36)**	-27.60	6.89	**(-41.12; -14.08)**	-10.42	7.64	(-25.41; 4.57)

● Control condition as reference ⁂ Similar as reference □ Comparison to analysis without sensory processing pattern (sensory processing pattern, see Table 2) BV = Bourdon-Vos, less = children who show sensory processing pattern behavior less than a reference group, more = children who show sensory processing pattern behavior more than a reference group. The model with sensory processing pattern contained intercept, test moment, test moment squared (for Bourdon-Vos measures), sensory processing tools (tangle, earmuffs, wobble cushion) and sensory processing pattern category (less, similar, more). Results printed in grey are of the models which were not significantly better than the model without sensory processing patterns, these results are printed here for completeness sake. Significant 95% CI are printed in bold.

[a]Comparison with analysis without sensory processing pattern (see Table 2).

[b]Control condition as reference.

[c]Similiar to others as reference category.

Discussion

The goal of the current study was to investigate whether the use of sensory processing tools had an acute effect on attention and arithmetic test performance and whether the effects were different among the categories "less than others," "similar to others," and "more than others" for each of the sensory processing patterns (registration, sensitivity, seeking, and avoiding).

No positive effects of the use of sensory processing tools on attention and arithmetic test performance in typically developing primary school children were found. In contrast, negative effects of using the tangle, earmuffs, and wobble cushion on the Bourdon–Vos total, using the tangle and wobble cushion on the Bourdon–Vos correct, and using the tangle on the arithmetic test were shown. In addition, for the Bourdon–Vos C ERR and O ERR, the model with sensory processing tools was not signif-

Table 4
Results of mixed-model analyses for the effects of sensory processing tools on Bourdon–Vos correct test scores for the sensory processing pattern *registration.*

	BV correct		
	b	*SE*	95% Confidence interval
Registration	−2LL = 9413.779, *df* = 18, *p* = .011[a]		
Intercept	133.74	4.74	[124.51, 142.97]
Test moment	49.31	3.24	**[43.00, 55.63]**
Test moment^2	−6.21	0.62	**[−7.41, −5.01]**
Tangle[b]	−13.51	2.30	**[−17.99, −9.04]**
Earmuffs[b]	−7.84	2.30	**[−12.32, −3.36]**
Wobble cushion[b]	−8.16	2.34	**[−12.72, −3.59]**
Registration–less[c]	−9.05	8.91	[−26.48, 8.37]
Registration–more[c]	−30.12	7.66	**[−45.10, −15.14]**
Tangle × less	12.15	6.11	**[0.24, 24.06]**
Earmuffs × less	18.23	5.82	**[6.89, 29.58]**
Wobble cushion × less	11.29	6.08	[−0.56, 23.13]
Tangle × less	13.04	5.11	**[3.08, 23.01]**
Earmuffs × less	10.95	5.14	**[0.93, 20.97]**
Wobble cushion × less	4.04	5.27	[−6.24, 14.32]

Note. Significant 95% confidence intervals are in bold. BV, Bourdon–Vos; −2LL, −2 log likelihood; less, children who showed sensory processing pattern behavior less than a reference group; more, children who showed sensory processing pattern behavior more than a reference group. The model with sensory processing pattern contained intercept, test moment, test moment squared, sensory processing tools (tangle, earmuffs, and wobble cushion), sensory processing pattern category (less than others, similar to others, and more than others), and sensory processing pattern category × sensory processing tools.
[a] Comparison with analysis with sensory processing pattern but without interaction (see Table 3).
[b] Control condition as reference.
[c] Similiar to others as reference category.

Table 5
Results of the mixed-model analyses effects of sensory processing tools on Bourdon–Vos correct test scores separate for children who were grouped in the categories "less than others," "similar to others," and "more than others" for sensory processing pattern *registration.*

	Less than others			Similar to others			More than others		
	b	*SE*	95% Confidence interval	*b*	*SE*	95% Confidence interval	*b*	*SE*	95% Confidence interval
Registration									
BV correct									
Intercept	106.72	14.64	**[78.34, 135.09]**	134.51	5.21	**[124.32, 144.70]**	113.14	9.34	**[94.97, 131.31]**
Test moment	66.10	10.59	**[45.59, 86.62]**	48.56	3.94	**[40.86, 56.26]**	41.16	6.13	**[29.25, 53.07]**
Test moment^2	−9.38	2.05	**[−13.35, −5.40]**	−6.02	0.75	**[−7.49, −4.55]**	−4.89	1.11	**[−7.05, −2.72]**
Tangle[a]	1.88	6.27	[−10.26, 14.03]	−13.59	2.34	**[−18.16, −9.02]**	−1.06	3.62	[−8.10, 5.98]
Earmuffs[a]	10.30	5.96	[−1.24, 21.84]	−7.83	2.34	**[−12.41, −3.26]**	2.30	3.66	[−4.82, 9.41]
Wobble cushion[a]	2.96	6.19	[−9.03, 14.95]	−8.27	2.38	**[−12.93, −3.61]**	−5.79	3.77	[−13.12, 1.55]

Note. Significant 95% confidence intervals are in bold. BV, Bourdon–Vos; Less than others, children who showed registration sensory processing pattern behavior less than a reference group; Similar to others, children who showed registration sensory processing pattern in a similar amount as a reference group; More than others, children who showed registration sensory processing pattern behavior more than a reference group. The model contained intercept, test moment, test moment squared, and sensory processing tools (tangle, earmuffs, and wobble cushion).
[a] Control condition as reference.

icantly better. Moreover, even when taking the sensory processing pattern of children into account, no significant effect of the use of sensory processing tools was shown with the exception of the sensory processing pattern *registration.* For *registration,* children who showed the behavior "similar to others"

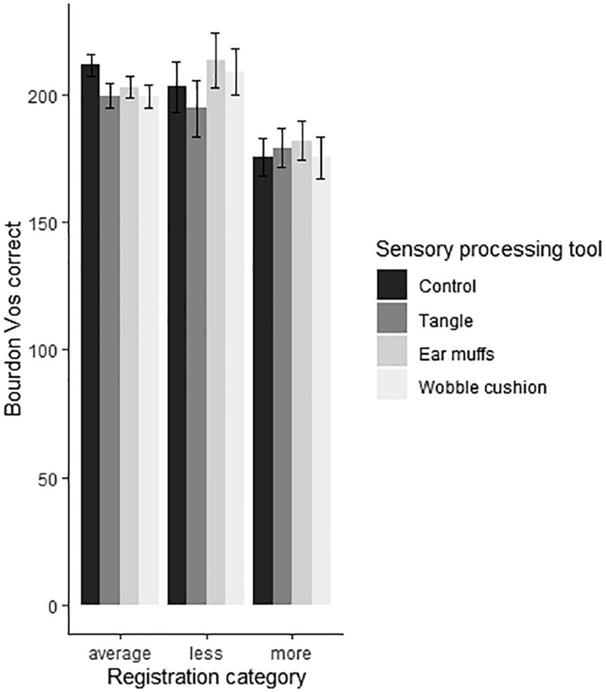

Fig. 2. Means and standard errors of the Bourdon–Vos correct test scores using different sensory processing tools separate for children who were grouped in the categories "less than others" (less), "similar to others" (average), and "more than others" (more) for the sensory processing pattern *registration*. The control condition was used as the reference category. Bars with an asterisk (*) represent a mean that is statistically significantly different from the control condition.

scored significantly worse on the Bourdon–Vos correct when using the sensory processing tools, whereas this was not the case for children who showed the behavior "less than others" or "more than others."

The findings from the current study regarding the tangle are in line with the limited amount of studies that have been executed on the effect of fidget toys. Both Amico and Schaefer (2020) and Soares and Storm (2019) showed a negative effect of fidget spinners compared with no use of a fidget spinner on memory performance in university students. However, the university students used the fidget toy while remembering words or watching a lecture, not while recalling the information. This is in contrast to the current study, in which children needed to use the tangle during the whole test session. In contrast to our findings, Stalvey and Brasell (2006) showed a positive effect when primary school children used a stress ball during writing instructions. Children showed fewer distractions and the mean writing score was improved. In contrast to the current study, children in the study of Stalvey and Brasell (2006) could decide for themselves if and when during the writing instructions they used the stress ball; it could be that students used the stress ball only when they needed it (i.e., when they needed extra stimuli). In addition, children used the stress ball three times a week over a 7-week period; it could be that a tangle would also show positive effects on attention and/or arithmetic performance if children could use it for an extended period of time and if they felt the need for using a tangle. Soares and Storm (2019) mentioned that the negative effects of the fidget spinner could possibly be caused by the novelty of the fidget spinner and that performing a secondary task (i.e., moving fidget spinner or tangle) can decrease performance on the first task (i.e., attention or arithmetic test) by diverting attention or overloading attentional limits. Both this novelty effect and the divided attention could also have caused the negative effects of the tangle in our current study. A longer intervention period could possibly abate the negative effects caused by the novelty of using a tangle.

When looking at classroom-based dynamic seating such as wobble cushions, Rollo et al. (2019) concluded in their review that dynamic seating could be an effective strategy to improve attention, but not academic performance, among elementary school students. In only a minority of studies the focus was on attention or academic performance. In addition, in three of the four studies that included attention, it was measured via a questionnaire mostly filled out by teachers (Fedewa & Erwin, 2011; Gaston et al., 2016; Pfeiffer et al., 2008). The only study that investigated attention measured with an objective neuropsychological test showed no effects of a cycling desk on the Rosvold continuous performance test (Torbeyns et al., 2017). In the Rosvold continuous performance test, letters are presented at a rate of one per second and students need to press the space bar if an X appears, with the test lasting for 7 min. The Rosvold test is similar to the Bourdon–Vos test in that both measure sustained attention. Rollo et al. (2019) concluded that there was no clear beneficial effect of classroom-based dynamic seating on academic performance; in two of the three studies they included, no significant effects of dynamic seating on academic performance were shown. The results from these previous studies are partially in line with the findings of the current study that no significant effect on arithmetic performance was shown when sensory processing pattern was not taken into account. However, the findings from previous studies are not in line with the finding in the current study that the wobble cushion led to decreased performance on both attention measures.

The fact that a negative effect of a wobble cushion on the attention measure was shown could, similar to the explanation for the results of using the tangle, be explained by the novelty effect and the fact that attention could have been diverted from the attention test to the wobble cushion. In addition, it has been suggested that wobble cushions can improve sensory processing due to the increase of proprioceptive and vestibular stimuli compared with a normal chair and that this improvement in sensory processing leads to improved learning (Rollo et al., 2019). However, for stimuli, more is not always better; it can be theorized that if a child already has enough proprioceptive and vestibular stimuli from a normal chair (i.e., the child's threshold is met), adding more proprioceptive and vestibular stimuli could lead to negative results.

The results regarding the effects of the earmuffs are largely in line with the results of Smith and Riccomini (2013), who showed no significant effect of earmuffs on reading comprehension. In the current study, no significant effects of earmuffs on Bourdon–Vos correct measure or arithmetic performance were shown. However, a negative effect of earmuffs on the Bourdon–Vos total measure was shown. Reading comprehension is a very different task than the Bourdon–Vos task, so it could be that tasks are influenced differentially by the presence or absence of noise. In the study of van Kempen, Van Kamp, Stellato, Houthuijs, and Fischer (2005), the relationship between noise caused by airports and cognitive measures was significant only for reading comprehension and switching attention but not for memory performance, attention, simple reaction times, and processing speed. The fact that we did not find an effect of earmuffs on the attention measure and the arithmetic test could also be caused by the fact that the study was executed in a relatively quiet classroom in a sort of exam setting; thus, there were not that many auditory stimuli to block.

It was also investigated whether the effects of sensory processing tools on the attention measures and arithmetic test performance were different for the categories "less than others," "similar to others," and "more than others" on each of the four sensory processing patterns (registration, sensitivity, seeking, and avoiding). The interaction between sensory processing pattern category and sensory processing tool significantly improved the model only for the sensory processing pattern *registration* specifically for the Bourdon–Vos correct measure. Additional subgroup analyses showed that the significant negative effect of sensory processing tools on Bourdon–Vos correct was present only in children who were classified as "similar to others" on the pattern *registration.* In other words, children who already received the optimal amount of stimuli performed worse on the Bourdon–Vos correct when stimuli were added or removed with sensory processing tools. The sensory processing tool × sensory processing pattern interaction was not significant for the other sensory processing patterns. However, the explorative subgroup analyses for those other three sensory processing patterns showed a similar trend. In general, a negative effect of the use of sensory processing tools compared with the use of no sensory processing tool was shown if children showed the sensory processing pattern behavior "similar to others," and nonsignificant effects of the use of the sensory processing tools compared with the use of no sensory processing tool were shown if children showed the sensory processing pattern behavior "more than others" and "less than others." Thus, it seems likely that sensory processing tools are in general negative for those children who already receive an optimal amount of stimuli. However, as far as the authors are aware, there are no earlier studies in which the sensory processing pattern of participants was taken into account when evaluating the effectiveness of sensory processing tools. Thus, the findings from the current study indicate that more research is needed. We also point out that post hoc power analyses for the interaction term showed that a sample size of 357 would have been needed to achieve a power of 80% (see Method). The power for the number of participants who were actually included was approximately 60% (i.e., variable due to different numbers of sensory profile category scores being available). Thus, even though our study was slightly underpowered, we were able to show a significant interaction effect. Future studies should ensure a more adequate power for their analyses.

Lastly, the results of the current study showed significant differences in scores on both the attention and arithmetic tests among the sensory processing pattern categories (i.e., "less than others," "similar to others," and "more than others"). Children in the "less than others" category scored mostly better on both the attention and arithmetic tests than children in the "similar to others" category. In addition, children in the "similar to others" category had in general higher attention and arithmetic scores than children in the "more than others" category. These differences were not significant for all outcome measures and sensory processing patterns, but they do point to the fact that sensory processing ability is related to attention and arithmetic performance. These results are in line with two previous studies that also showed a significant correlation between sensory processing and arithmetic performance (Jirikowic et al., 2008; Parham, 1998). Note that in these studies other measures to assess sensory processing were used, namely the Short Sensory Profile (Jirikowic et al., 2008) and the Sensory Integration and Praxis test (Parham, 1998), and these studies included both typically developing children and children with fetal alcohol spectrum disorder (Jirikowic et al., 2008) and children with learning disorders (Parham, 1998). All in all, nonoptimal sensory processing, specifically showing "the behavior more than others", seems to be related to decreased attention and arithmetic performance in comparison with optimal sensory processing.

The current study had a number of limitations. Sensory processing tools were used in a one-time test situation, and the sensory processing tool used was not adapted to the sensory processing pattern of the child. It could be that if a child receives a personalized sensory processing tool for a longer time period and can use it during instruction lessons or at other moments when the child needs extra stimuli or needs stimuli to be removed, the effects of the sensory processing tools would be positive. This warrants future research, although caution is advised because any negative effect could also be amplified when the sensory processing tools are used for a longer period of time.

In the current study, three sensory processing tools were used that are already available at many schools, are cheap, are not a nuisance for the teacher or other students, and either add stimuli (i.e., tangle and wobble cushion) or remove stimuli (i.e., earmuffs). However, the tangle might not have been appropriate for the setting of the current study. It was noticed that many children found it difficult to handle the tangle in one hand and cross out the Bourdon–Vos stimuli with the other hand, especially as the sheet of paper would sometimes slip away. Furthermore, some children experienced the earmuffs as annoying because they felt the pressure on their ears and/or their ears got warm; in other words, the earmuffs not only removed auditory stimuli but also added pressure and temperature stimuli. These observations should be taken into account when designing future intervention studies.

A vast array of sensory processing tools is available, ranging from study buddies (i.e., a collapsible wooden construction that can be put on the desk of a child to shield visual stimuli), to chewing toys, to pressure vests. It could be the case that other sensory processing tools than the ones used in the current study would have shown positive effects. Thus, more research is needed to investigate other sensory processing tools preferably personalized to students' needs.

The current study had a number of important strengths. This is one of the first studies to investigate the effects of sensory processing tools on attention and arithmetic performance that included such a large number of typically developing children attending a regular primary school. In the current study, 29.1–36.3% of children had nonoptimal sensory processing. Because nonoptimal sensory processing is so common in primary school children, and because there were significant differences in the scores on the Bourdon–Vos and arithmetic tests among the sensory processing pattern categories, it is important that more research on this topic be executed in primary school children. Moreover, this is one of the first studies to include a number of sensory processing tools and to take into account that these sensory processing tools might differentially affect children with different sensory information processing patterns.

Conclusion

No positive effects of sensory processing tool use on attention and arithmetic tests were shown in second-grade children in the current study, with the effect of some sensory processing tools on attention and arithmetic test performance even being negative. Even when taking the sensory processing pattern of each individual child into account, no significant positive effects of sensory processing tool use on attention and arithmetic tests were shown. Lastly, children with nonoptimal sensory processing who showed sensory processing pattern behaviors "more than others" had lower performance on attention and arithmetic tests than children who showed sensory processing pattern behavior "similar to others." Considering these results, more research is needed to investigate the effects of longer-term personalized sensory processing tool use on attention and arithmetic performance of children.

CRediT authorship contribution statement

Inge van der Wurff: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration, Funding acquisition. **Celeste Meijs:** Conceptualization, Methodology, Investigation, Writing - review & editing, Supervision, Project administration, Funding acquisition. **Petra Hurks:** Conceptualization, Methodology, Investigation, Writing - review & editing, Supervision, Funding acquisition. **Christine Resch:** Conceptualization, Investigation, Writing - review & editing. **Renate de Groot:** Conceptualization, Methodology, Writing - review & editing, Supervision, Funding acquisition.

Acknowledgments

This work was supported by the Netherlands Initiative for Education Research (NRO) under Grant [number 405-18-644]. We like to thank all participants, schools and school boards who participated in WOBBLE. Furthermore, we like to thank the dedicated research assistance of Mara Kirschner and the occupational therapist Karin Hilkens for their immense input.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2021.105143.

References

Amico, G., & Schaefer, S. (2020). No evidence for performance improvements in episodic memory due to fidgeting, doodling or a "neuro-enhancing" drink. *Journal of Cognitive Enhancement, 4*, 2–11.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*(1). https://doi.org/10.18637/jss.v067.i01.

Ben-Sasson, A., Carter, A., & Briggs-Gowan, M. (2009). Sensory over-responsivity in elementary school: Prevalence and social-emotional correlates. *Journal of Abnormal Child Psychology, 37*, 705–716.

Ben-Sasson, A., Hen, L., Fluss, R., Cermak, S. A., Engel-Yeger, B., & Gal, E. (2009). A meta-analysis of sensory modulation symptoms in individuals with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 39*, 1–11.

Brown, T., Morrison, I. C., & Stagnitti, K. (2010). The convergent validity of two sensory processing scales used with school-age children: Comparing the Sensory Profile and the Sensory Processing Measure. *New Zealand Journal of Occupational Therapy, 57*(2), 56–65.

Cheung, P. P., & Siu, A. M. (2009). A comparison of patterns of sensory processing in children with and without developmental disabilities. *Research in Developmental Disabilities, 30*, 1468–1480.

Dunn, W. (1997). The impact of sensory processing abilities on the daily lives of young children and their families: A conceptual model. *Infants and Young Children, 9*, 23–35.

Dunn, W., & Bennett, D. (2002). Patterns of sensory processing in children with attention deficit hyperactivity disorder. *OTJR: Occupation, Participation and Health, 22*(1), 4–15.

Dunn, W., & Rietman, A. (2013). SP-NL: Sensory Profile, herziene Nederlandse editie. Amsterdam, Nederland: Pearson Benelux B. V.

Egberink, I. J. L., Leng, W. E., & Vermeulen, C. S. M. (1997). COTAN beoordeling Bourdon–Vos [COTAN review of the Bourdon–Vos]. Retrieved November 28, 2019, from https://www.cotandocumentatie.nl/beoordelingen/b/13678/bourdon-vos-test/.

Ermer, J., & Dunn, W. (1998). The Sensory Profile: A discriminant analysis of children with and without disabilities. *American Journal of Occupational Therapy, 52*, 283–290.

Fedewa, A. L., & Erwin, H. E. (2011). Stability balls and students with attention and hyperactivity concerns: Implications for on-task and in-seat behavior. *American Journal of Occupational Therapy, 65*, 393–399.

Gaston, A., Moore, S., & Butler, L. (2016). Sitting on a stability ball improves attention span and reduces anxious/depressive symptomatology among Grade 2 students: A prospective case-control field experiment. *International Journal of Educational Research, 77*, 136–142.

Ghanizadeh, A. (2011). Sensory processing problems in children with ADHD: A systematic review. *Psychiatry Investigation, 8*(2), 89–94.

Green, P., & MacLeod, C. J. (2016). SIMR: An R package for power analysis of generalized linear mixed models by simulation. *Methods in Ecology and Evolution, 7*, 493–498.

Jirikowic, T., Olson, H. C., & Kartin, D. (2008). Sensory processing, school performance, and adaptive behavior of young school-age children with fetal alcohol spectrum disorders. *Physical & Occupational Therapy in Pediatrics, 28*, 117–136.

Lenth, R. V., Buerkner, P., Herve, M., Love, J., Riebl, H., & Singmann, H. (2020). emmeans: Estimated marginal means, aka least-squares means. *American Statistician, 34*, 216–221.

Little, L., Dean, E., Tomchek, S., & Dunn, W. (2017). Classifying sensory profiles of children in the general population. *Child: Care, Health and Development, 43*(1), 81–88.

Marco, E. J., Hinkley, L., Hill, S. S., & Nagarajan, S. S. (2011). Sensory processing in autism: A review of neurophysiologic findings. *Pediatric Research*. 69(5, Pt 2), 48R–54R.

Ohl, A., Butler, C., Carney, C., Jarmel, E., Palmieri, M., Pottheiser, D., & Smith, T. (2012). Test–retest reliability of the Sensory Profile Caregiver Questionnaire. *American Journal of Occupational Therapy, 66*, 483–487.

Parham, L. D. (1998). The relationship of sensory integrative development to achievement in elementary students: Four-year longitudinal patterns. *Occupational Therapy Journal of Research, 18*(3), 105–127.

Pfeiffer, B., Henry, A., Miller, S., & Witherell, S. (2008). Effectiveness of Disc 'O' Sit cushions on attention to task in second-grade students with attention difficulties. *American Journal of Occupational Therapy, 62*, 274–281.

Pinheiro, J., Bates, D., DebRoy, S., & Sarkar, D. (2007). nlme: Linear and nonlinear mixed effects models. Retrieved from https://CRAN.R-project.org/package=nlme.

Reynolds, S., & Lane, S. J. (2008). Diagnostic validity of sensory over-responsivity: A review of the literature and case reports. *Journal of Autism and Developmental Disorders, 38*, 516–529.

Rollo, S., Crutchlow, L., Nagpal, T. S., Sui, W., & Prapavessis, H. (2019). The effects of classroom-based dynamic seating interventions on academic outcomes in youth: A systematic review. *Learning Environments Research, 22*, 153–171.

Schecter, R. A., Shah, J., Fruitman, K., & Milanaik, R. L. (2017). Fidget spinners: Purported benefits, adverse effects and accepted alternatives. *Current Opinion in Pediatrics, 29*, 616–618.

Smith, G. W., & Riccomini, P. J. (2013). The effect of a noise reducing test accommodation on elementary students with learning disabilities. *Learning Disabilities Research & Practice, 28*(2), 89–95.

Soares, J. S., & Storm, B. C. (2019). Putting a negative spin on it: Using a fidget spinner can impair memory for a video lecture. *Applied Cognitive Psychology, 34*, 277–284.

Stalvey, S., & Brasell, H. (2006). Using stress balls to focus the attention of sixth-grade learners. *Journal of At-Risk Issues, 12*(2), 7–16.

Torbeyns, T., de Geus, B., Bailey, S., Decroix, L., Van Cutsem, J., De Pauw, K., & Meeusen, R. (2017). Bike desks in the classroom: Energy expenditure, physical health, cognitive performance, brain functioning, and academic performance. *Journal of Physical Activity and Health, 14*, 429–439.

van der Linde, J., Franzsen, D., & Barnard-Ashton, P. (2013). The Sensory Profile: Comparative analysis of children with specific language impairment, ADHD and autism. *South African Journal of Occupational Therapy, 43*(3), 34–40.

van Kempen, E., Van Kamp, I., Stellato, R., Houthuijs, D., & Fischer, P. (2005). Het effect van geluid van vlieg-en wegverkeer op cognitie, hinderbeleving en de bloeddruk van basisschoolkinderen [The effect of aircraft and road traffic noise on the cognitive performance, annoyance and blood pressure of primary school children]. Retrieved May 20, 2020, from https://www.rivm.nl/bibliotheek/rapporten/441520021.html.

Verbeke, G., & Molenberghs, G. (2009). Linear mixed models for longitudinal data. In G. Verbeke & G. Molenberghs (Eds.), *Linear mixed models in practice: A SAS-oriented approach*. New York: Springer.

Vos, P. (1998). *Bourdon Vos testhandleiding [Bourdon–Vos test manual]*. Lisse, The Netherlands: Swets & Zeitlinger.

Wekselblatt, J. B., & Niell, C. M. (2015). Behavioral state—Getting "in the zone". *Neuron, 87*, 7–9.