

SHORT PAPER

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The effect of retrieval practice on fluently retrieving multiplication facts in an authentic elementary school setting

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Abstract

Fluently retrieving simple multiplication facts leads to an improvement of overall math scores. In the current study, we investigated how to best reach this fluency in an authentic elementary school setting. We compared the short-term and long-term effects of the learning strategies retrieval practice (using flashcards) to a restudy control condition (chanting multiplication facts out loud) on multiplication fact fluency. Forty-eight second-grade pupils received an instruction lesson and attended three spaced practice sessions per learning strategy. The learning strategies were counter-balanced across two different sets of multiplication tables in a within-subjects design. A pre-test, a five-minute delay post-test, and a one-week delay post-test were administered. Compared to restudy, retrieval practice led to a stronger short-term and long-term increase in the fluency of retrieving multiplication facts. This study demonstrates the effectiveness of retrieval practice on gaining multiplication fact fluency in an authentic classroom setting using original course materials.

KEYWORDS

classroom setting, elementary school, learning strategies, multiplication facts, retrieval practice

1 | INTRODUCTION

Fluently retrieving simple multiplication facts (e.g., $2 \times 4 = 8$) is included as a goal in elementary school math curricula across the world (e.g., Alcock et al., 2016; Common Core State Standards Initiative, 2010; Department for Education, 2013; National Council for Teachers of Mathematics [NCTM], 2000). Quickly and accurately retrieving the answer to a simple multiplication problem (i.e., $2 \times 4 = \dots$), referred to as multiplication fact fluency, increases overall math scores (e.g., Campbell & Xue, 2001; Dotan & Zviran-Ginat, 2022; García-Orza et al., 2021; Hasselbring et al., 1988), and provides the foundation for dealing with a great diversity of numerical-problem-solving situations in everyday life (Campbell & Xue, 2001; García-Orza et al., 2021; National Mathematics Advisory Panel [NMAP], 2008).

For their pupils to acquire multiplication fact fluency, teachers use a variety of learning strategies, such as coloring in table squares, doing

tests, writing down the facts, “looking at them,” listening to tapes, chanting them out loud, or using flashcards (e.g., Olfos & Isoda, 2021; Steel & Funnell, 2001). Although these learning strategies are often applied in combination (drill, practice, and modeling, see Codding et al., 2011) and this produces positive effects on acquiring multiplication fact fluency, it remains unclear which learning strategy causes this effect and is used best to enhance pupils' multiplication fact fluency in an authentic elementary school setting (e.g., García-Orza et al., 2021; NMAP, 2008).

1.1 | Multiplication fact fluency

A number of factors are known to influence the fluency of retrieving the answer to a simple multiplication problem (e.g., Ashcraft & Guillaume, 2009; Campbell & Graham, 1985; De Brauwier et al., 2006;

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Katzoff et al., 2020; Koshmider & Ashcraft, 1991; Noel & De Visscher, 2018; Van der Ven et al., 2015). For example, large problems (containing the operands 6, 7, and 8) are more difficult to solve than small problems (the problem size effect, for a review, see Ashcraft & Guillaume, 2009), problems with equal operands (e.g., $3 \times 3 = 9$ and $4 \times 4 = 16$) are easier to solve than problems with unequal operands (the tie effect, e.g., Campbell & Graham, 1985; De Brauwer et al., 2006), facts that look similar (e.g., $8 \times 6 = 48$ and $8 \times 8 = 64$) are harder to memorize than facts that look different (the similarity effect, e.g., Katzoff et al., 2020; Noel & De Visscher, 2018), and specific operands make a problem relatively easy to solve, such as problems containing the operand 1, 2, 5, or 9 (the operand effects, e.g., Campbell & Graham, 1985; De Brauwer et al., 2006).

Learners overcome these difficulties using diverse strategies to retrieve the answer to a simple multiplication problem (e.g., Campbell & Xue, 2001; Koshmider & Ashcraft, 1991; Siegler, 1988). These strategies range from direct retrieval from long-term memory to more procedural strategies, such as deriving the answer from another known fact (e.g., recognizing 3×4 as 4×3) or additional counting (3, 6, 9, 12, etc.). Retrieving the answer from memory is found to be the fastest and least error-prone strategy (Steel & Funnell, 2001). When early adulthood is reached, direct retrieval is the strategy that is almost exclusively used to solve simple multiplication problems (Campbell & Xue, 2001). However, relatively few children (18% of 12-year-olds) use this effective strategy for all simple multiplication problems (Steel & Funnell, 2001). Instead, they mostly rely on slower and less accurate procedural strategies, such as deriving the answer from another known fact (Steel & Funnell, 2001). This finding is concerning, because when children cannot rely on multiplication fact fluency, their working memory becomes overloaded when more complex math problems, such as divisions, calculating percentages, and multi-digit multiplications need to be solved, which eventually will negatively influence the overall math scores (e.g., Bryant et al., 2008; Fuchs et al., 2008; García-Orza et al., 2021). To be able to count on direct retrieval when solving simple multiplication problems, children need effective learning strategies that help them to encode these facts in long-term memory, such as retrieval practice (for reviews, see Adesope et al., 2017; Agarwal et al., 2021).

1.2 | Retrieval practice

Retrieval practice (i.e., retrieving to-be-learned information from memory) as a learning strategy leads to better long-term retention of knowledge than does additional restudy (for reviews, see Adesope et al., 2017; Agarwal et al., 2021). This effect is found for adolescents and adults in both laboratory and classroom settings (e.g., Adesope et al., 2017; Agarwal et al., 2021), and increases when practice sessions are spaced over time (for a review, see Carpenter et al., 2022), and feedback is given (e.g., Kang et al., 2007; Lipko-Speed et al., 2014). Despite these promising effects, there is still a lot to learn about the short-term and long-term effects of retrieval practice. Especially when it comes to pupils learning arithmetic facts, such as the simple multiplication facts, in an authentic classroom setting (Agarwal et al., 2021).

Classroom research for retrieval practice is defined as research in which relevant course materials are used, individual retrieval practice is supervised by researchers and instructors, and retrieval practice is done without access to an open book (Agarwal et al., 2021). In their recent review, Agarwal et al. (2021) only found three elementary-school studies including five experiments that met the described classroom criteria. These experiments were all conducted in the language domain (Goossens et al., 2016; Jones et al., 2016; Karpicke et al., 2016). Four of these experiments showed positive short-term effects for retrieval practice in the domain of spelling (Jones et al., 2016) and learning wordlists (Karpicke et al., 2016), whereas one experiment did not show an advantage for retrieval practice on vocabulary learning (Goossens et al., 2016). Because of the mixed results and the focus on the language domain, it is unclear if these overall positive findings generalize to the domain of math. It is also not clear if these short-term effects hold for the long term. When it comes to short-term and long-term retrieval practice effects, there is a difference in findings between laboratory research and classroom research (Agarwal et al., 2021). Compared to restudy, classroom research shows larger short-term than long-term benefits for retrieval practice (Agarwal et al., 2021), whereas laboratory research often only shows long-term benefits for retrieval practice (e.g., Roediger & Karpicke, 2006; Wheeler et al., 2003). Assessing the long-term effects of retrieval practice in classroom research is also relevant from a practical point of view, because multiplication fact fluency is needed throughout a pupil's entire math career (Campbell & Xue, 2001; García-Orza et al., 2021; NMAP, 2008).

In sum, it is unclear if the learning strategy retrieval practice has positive short-term and long-term effects on acquiring multiplication fact fluency in an authentic elementary school classroom setting. Therefore, we compared the effect of retrieval practice (in the form of flashcards) on the multiplication fact fluency of second-grade pupils to the effect of the learning strategy restudy (control condition). To represent the learning strategy restudy, we chose the commonly used strategy of chanting the tables out loud, in which pupils jointly recite the multiplication facts (Steel & Funnell, 2001). We conducted this study in four authentic classrooms, with teachers executing the research, and using authentic course material. The experiment was guided by the following research question.

Compared to restudy, what is the short-term and long-term effect of retrieval practice on the multiplication fact fluency of second-grade pupils?

2 | METHOD

2.1 | Design

A 2×3 within-subjects design was used, with the independent variables “learning strategy” (retrieval practice and restudy) and “time” (pre-test, short-term post-test, and long-term post-test). The dependent variable was the test score on a simple multiplication problem test. The schedule of practice and test sessions is summarized in Table 1.

TABLE 1 Distribution of instruction lessons (instruction), restudy sessions (RS), retrieval practice sessions (RP), and tests (ST, short-term and LT, long-term).

Class	Day 14	Week 1 and 2: Table of 3				Week 3 and 4: Table of 4			
		Day 1	Day 3	Day 4	Day 11	Day 1	Day 3	Day 4	Day 11
1 and 2	Pre-test	Instruction RS	RS	RS ST-test	LT-test	Instruction RP	RP	RP ST-test	LT-test
3 and 4	Pre-test	Instruction RP	RP	RP ST-test	LT-test	Instruction RS	RS	RS ST-test	LT-test

2.2 | Participants

To conduct a 2×3 within-subjects Repeated Measures ANOVA with a power of 95% and an alpha level of 5% (Cohen's f effect size of 0.25, based on a meta-analyze of Rowland, 2014), 28 participants were required (G*power, version 3.1.9.7). Since multiplication facts were first introduced in the second grade of elementary school, we approached the parents of 90 second-grade pupils from three schools and secured informed consent. This resulted in 54 participants without reported learning disorders, such as dyslexia and dyscalculia. Six pupils were absent during one or more practice or test sessions, resulting in a final sample of 48 participants (mean age = 6.96, SD = .43).

2.3 | Materials

2.3.1 | Multiplication facts

In many Western countries, simple multiplication facts are organized in a matrix, known as the multiplication table, encompassing 100 simple multiplication facts ranging from 1 to 10. To be able to counterbalance learning strategies across facts derived from the multiplication table in our within-subjects design, the table sets of the operands three and four were selected from the multiplication table. These two sets were selected due to their comparable degree of difficulty (Van der Ven et al., 2015).

2.3.2 | Pre-test and post-tests

To assess prior knowledge, a pre-test was constructed. The design of the pre-test and both the post-tests was based on the Tempo Toets Rekenen (TTR, De Vos, 1992), a widely used Dutch test for measuring multiplication fact fluency in elementary education. This TTR contains eight sets of five mixed multiplication problems (40 sums), covering all 10 multiplication sets. Pupils receive 1 min to write down the answer to as much multiplication problems possible. In the TTR, fluency is defined by the number of correct answers written down within 1 min. The TTR was adjusted, because instead of measuring the fluency of all 10 multiplication sets, we only measured the fluency on, respectively, the multiplication table set of 3 and 4. The test existed of four pages on which two sets of five sums (a total of 40 sums) were displayed in a mixed order. To prevent participants from copying a previously

generated answer, only 10 sums were displayed per page. For each correct answered multiplication problem, participants achieved 1 point, with a maximum of 40 points. It was however not expected that any participant at this age would be able to answer the 40 given multiplication problems within a one-minute timeframe, because the TTR is administered from second up to sixth grade. It is for this reason that we interpreted absolute scores instead of percentages for our analysis. In the pre-test and the post-tests, the same items were used, but their order was varied to lower the chances of a test-effect, as in memorizing the order of answers from a previous test (Creswell, 2012).

2.3.3 | Instruction lesson

In collaboration with the participating teachers, a PowerPoint instruction lesson was created based on the schools' course material. The lesson covered either the multiplication set of 3 or 4, presenting the 10 multiplication facts sequentially from 1 to 10 (i.e., 1×3 – 10×3), accompanied by a logical explanation matching each fact (i.e., 1×3 means: "If I grab three apples, and I do this only one time, how many apples do I have?"). To keep conditions in classrooms as equal as possible, a script was constructed by the researcher. At the end of the PowerPoint lesson, a sheet with all 10 multiplication facts was displayed to jointly recite.

2.3.4 | Restudy materials

For the restudy practice sessions, a PowerPoint sheet (derived from course material) representing the multiplication facts from low to high (e.g., $1 \times 3 = 3$ up to $10 \times 3 = 30$), was used for both the multiplication table set of three and four. A script with teacher instructions was added, to maintain equality between groups.

2.3.5 | Retrieval practice materials

For each participant, a set of 10 flashcards for both the multiplication tables of 3 and 4 and a personal flashcard booklet were developed. The flashcards were chosen because they were part of the course material and because flashcards provide direct feedback, which is a moderator of retrieval practice (for a review, see Agarwal et al., 2021). These flashcards had a simple multiplication problem on the front

side of the card and the answer to that problem on the back side of the card. The personal flashcard booklet consisted of 10 stapled cards depicting the multiplication problems without their answer (e.g., $1 \times 3 =$, etc.), and a front cover that displayed 4 numbered boxes.

2.4 | Procedure

Prior to this experiment a pilot study with eleven second grade pupils was conducted to test the materials' proper use within the allotted time. Based on this pilot, the time on task was reduced from 10 to 5 min.

Two weeks prior to the experiment, the pre-test was administered in four second grade classes across three elementary schools. Teachers were asked not to practice the multiplication tables in any other way during the experimental period. Two weeks after the pre-test was administered, the participants in both conditions received the instruction lesson on the table of three. The teacher used the PowerPoint sheet to read each multiplication fact out loud and explain the meaning of each fact. Following this instruction lesson, two of the four classes practiced their instructed multiplication table set using the learning strategy restudy, while the other two classes practiced with retrieval practice. Within 1 week, three practice sessions were conducted (see Table 1).

During the restudy practice sessions, the multiplication facts of the table set of three were displayed on the digital whiteboard, using the PowerPoint sheet. These multiplication facts were collectively recited aloud five times within a five-minute timeframe, following a fixed sequence from $1 \times 3 = 3$ up to $10 \times 3 = 30$. The practice alternated between two rounds in unison, one round with half the children chanting the multiplication facts out loud while the others listened (to control for correctness), then vice versa, and concluded with one final round in unison. Each practice session lasted approximately 5 min (± 30 s). The researcher was present to monitor the time on task and the correct implementation of the strategy.

In the retrieval practice condition, each pupil received a set of flashcards as described in the material section. During these sessions the participants individually practiced with their set of flashcards for five times in 5 min, equal to the restudy condition. The teachers instructed their pupils to first read the multiplication problem, then try to recall the answer from their memory, before turning the card around to receive feedback on their answer. To prevent a different practice order to interfere with final results, the flashcards had to be practiced within a fixed order from $1 \times 3 =$ up to $10 \times 3 =$, equal to the restudy condition. To ensure that pupils actually practiced the multiplication facts five times, they received the personal flashcard booklet. After each of the first 4 rounds of practice with the 10 flashcards, the pupils had to tick one of the 4 boxes on the front cover of the personal flashcard booklet. In the fifth round, pupils stowed their flashcards and opened their personal flashcard booklet to answer the 10 multiplication problems contained within. This approach allowed us to determine if participants engaged in retrieval practice at least once and to what

extent initial retrieval occurred (with a maximum of 10 correctly answered multiplication facts). When participants completed their task before the allocated 5 min (± 30 s), they silently awaited their classmates to finish. The researcher was present to monitor the time on task and the correct implementation of the strategy.

Five minutes after the third practice session, the short-term post-test for the multiplication table set of three was administered. Participants were tasked to fill in as many answers to a mix of simple multiplication problems as possible, within a 1-min timeframe. One week later the long-term post-test was administered in the same way.

Four days after the long-term post-test, the participants received their instruction lesson on the multiplication facts of the table set of four. After this instruction the practice sessions started. The participants that practiced the multiplication table set of three by restudy, now used the learning strategy retrieval practice and vice versa (see Table 1). Five minutes after the third practice session, the post-test short-term for the multiplication table set of four was administered. One week later the long-term post-test was administered.

2.5 | Transparency and openness

The development of the research materials and the data collection took place in 2022. The materials and data are available at the DANS Easy repository, <https://doi.org/10.17026/dans-z8h-c463>. Data were analyzed using IBM SPSS Statistics (Version 27, 2020). This study's design and its analysis were not pre-registered.

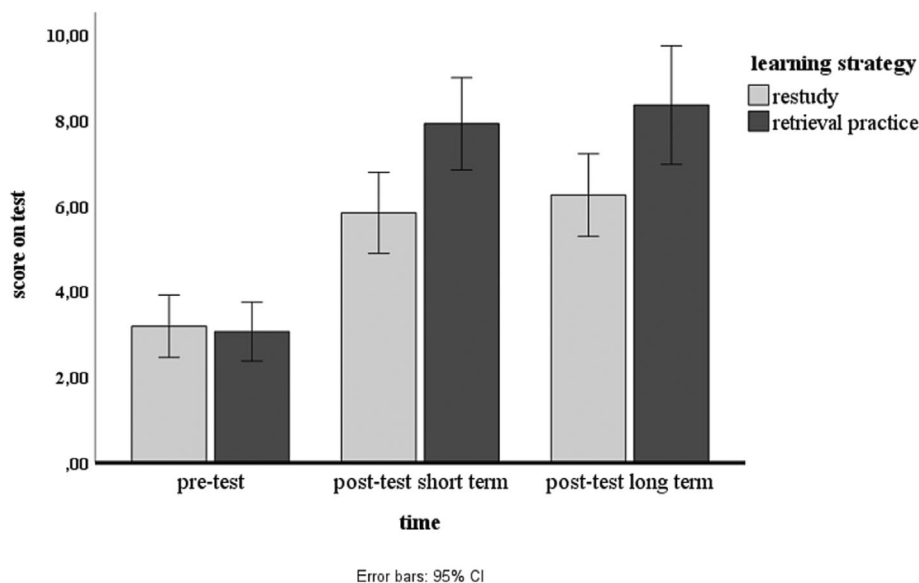
3 | RESULTS

Analyzing the pre-test scores, no significant difference was found between conditions, $t(47) = .60$, $p = .55$, $d = .09$. Also, the mean correct answers (maximum of 10) in the personal flashcard booklets were calculated for each of the three flashcard practice sessions. These were respectively $M = 8.7$ ($SD = 2.6$), $M = 9.2$ ($SD = 1.8$), and $M = 9.0$ ($SD = 2.3$).

3.1 | The effect of retrieval practice and restudy on the multiplication fact fluency over time

According to Byrne's guidelines (2010), all test-scores were normally distributed. Also, the assumption of sphericity was met for all analysis. To answer the research question, a within-subjects Repeated Measures ANOVA with the two independent variables "learning strategy" (restudy and retrieval practice) and "time" (pre-test, post-test short-term, and post-test long-term) was conducted. The dependent variable was the test score on the different multiplication problem tests. The Repeated Measures ANOVA resulted in a significant large main effect for the variable "time," $F(2, 94) = 76.86$, $p < .001$, $\eta_p^2 = .62$, indicating that the multiplication fact fluency increased over time. Also, a significant large main effect was found for the variable

FIGURE 1 Test scores per learning strategy over time.



“learning strategy,” $F(1, 47) = 16.13$, $p < .001$, $\eta_p^2 = .26$. The effect of the learning strategy retrieval practice on test scores was significantly higher than the effect of the learning strategy restudy. Finally, an interaction effect was found between time and learning strategy, $F(2, 94) = 15.12$, $p < .001$, $\eta_p^2 = .24$. This is a large effect according to Cohen's threshold values for effect sizes (Cohen, 1988). Hence, participants using retrieval practice showed a significantly higher increase in multiplication fact fluency over time than participants using restudy (see Figure 1).

Simple contrasts were analyzed to determine differences between learning strategies over time. First, we found a larger increase in scores from the pre-test to the short-term post-test for retrieval practice compared to restudy, $F(1, 47) = 19.17$, $p < .001$, $\eta_p^2 = .29$. The learning strategy retrieval practice led to stronger short-term growth than the learning strategy restudy. This is a large positive effect according to Cohen's threshold values for effect sizes (Cohen, 1988). Second, we found a larger increase in scores from the pre-test to the long-term post-test for retrieval practice compared to restudy, $F(1, 47) = 23.83$, $p < .001$, $\eta_p^2 = .34$. The learning strategy retrieval practice led to stronger long-term growth than the learning strategy restudy. This is a large positive effect according to Cohen's threshold values for effect sizes (Cohen, 1988). Finally, we found no difference of increase in scores from the short-term post-test to the long-term post-test for retrieval practice compared to restudy, $F(1, 47) = .002$, $p = .96$, $\eta_p^2 = .00$. Differences between short-term and long-term effects of both learning strategies were comparable.

4 | DISCUSSION AND CONCLUSION

This research examined the short-term and long-term effects of the two commonly used learning strategies retrieval practice and restudy on acquiring multiplication fact fluency in an authentic classroom setting. The results show that both learning strategies have a positive

effect on multiplication fact fluency over time. However, compared to restudy, retrieval practice leads to a stronger increase of both short-term and long-term multiplication fact fluency. Additionally, for both learning strategies, pupils retained their short-term fact fluency for over a week.

First, the current study extends the positive effects of retrieval practice compared to restudy to the domain of elementary school mathematics learning. This is in line with the majority of previously conducted elementary school classroom experiments investigating the effects of retrieval practice in the language domain (Jones et al., 2016; Karpicke et al., 2016). It must be noted that this extension applies to a specific form of factual arithmetic knowledge (multiplication facts) and it is thus unclear if the positive effect of retrieval practice also holds for fluently retrieving other examples of factual arithmetic knowledge (i.e., simple addition and subtraction, which also predict overall math scores, Campbell & Xue, 2001; NMAP, 2008) or for learning procedural aspects of elementary school mathematical knowledge. Both are interesting directions for future research.

Interestingly, the positive effect of retrieval practice compared to restudy in our study appeared on the short-term test and the effect did not dissipate after a one-week delay. This appears to contrast with the general finding in classroom studies that short-term effects of retrieval practice are larger than long-term effects (Agarwal et al., 2021). It also contrasts with laboratory research in which only long-term benefits of retrieval practice were found that were attributed to a smaller rate of forgetting compared to restudy (Roediger & Karpicke, 2006; Wheeler et al., 2003).

The contrast with the finding of Agarwal et al. (2021) might be explained by the difference in the retention interval (the time between the last practice session and the final test). In our study, the long-term effect was measured after a 1-week delay, while the long-term effect in the review of Agarwal et al. (2021) was based on a 6–15 weeks delay. It is possible that forgetting did not yet occur after 1 week, but would have occurred after 6–15 weeks. Future research

should examine different long-term time-delays of final tests to extend knowledge on the long-term effects of retrieval practice in an elementary school classroom setting.

An explanation for the comparable rate of forgetting between retrieval practice and restudy, which is in contrast with previous laboratory research (Roediger & Karpicke, 2006; Wheeler et al., 2003), might be that by administering the short-term test, our restudy group also received a form of retrieval practice. Five minutes after their last practice session they tested their knowledge of the to-be-learned multiplication tables in the short-term test, which might have reduced the rate-of forgetting. To control for this limitation, follow-up research could be conducted in which this short-term test is eliminated. In any case, this does not detract from the finding that retrieval practice demonstrated a larger growth in multiplication fact fluency compared to restudy from pre-test to both the short-term and the long-term test.

Another limitation of this study is the difference in practice format between the two learning strategy conditions. In the restudy condition, practice was conducted as a class, whereas in the retrieval practice condition, practice was done individually. This difference might be interpreted as a potential confound. However, in order to maintain ecological validity, we wanted to stay true to a commonly used restudy method. We concluded that when chanting aloud as a class, pupils follow their teacher's rhythm and are, each individually, stimulated to restudy all multiplication facts in the given order. Also, chanting aloud in a group allows both the teacher and the researcher to observe whether each pupil actively participates, something that is difficult to monitor when, for example, each pupil receives a card that displays the multiplication facts for individual restudy. Therefore, we determined that, in a classroom setting, "chanting the tables out loud" is the most authentic and suitable method to have each pupil restudy the simple multiplication facts.

In conclusion, this study, conducted in an authentic classroom setting with the use of authentic materials and with teachers conducting the experiment, showed an advantage for retrieval practice (using flashcards) compared to restudy (chanting the tables out loud) in enhancing the multiplication fact fluency of second-grade elementary school pupils. This implies that it can be expected that the use of retrieval practice through flashcards contributes to an improvement in pupils' multiplication fact fluency when used in an elementary school classroom setting.

AUTHOR CONTRIBUTIONS

Fieke Ophuis-Cox, Leen Catrysse, and Gino Camp designed the study in cooperation. Fieke Ophuis-Cox, PhD candidate, planned and conducted the research. She also took the lead in developing the theoretical framework, performing the analyses, and writing the manuscript. These processes were carried out in close collaboration with Leen Catrysse as the daily supervisor and Gino Camp as the promotor.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data for this study will be publicly accessible through DANS Easy (<https://doi.org/10.17026/dans-29b-q7q9>). The data will be preserved for at least 10 years. Facilities for FAIR data storage are provided by the Open University of the Netherlands.

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