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Does cyberspace increase young children's numerical performance? A brief overview from the perspective of cognitive neuroscience

1. Introduction

Representations of numbers, in particular representations of symbolic numbers (for review of the differences between representations of symbolic and non-symbolic numbers, see: Blanco-Elorrieta & Pylkkanen, 2016; Houde & Tzourio-Mazoyer, 2003; Iversen et al., 2006; Lyons, Ansari & Beilock, 2015; Nieder, 2005), remain closely related to representations of language and representations of praxis. In the context of the relation with representations of language, it is said that language is indispensable to processing precise numerical values, and sometimes even that numbers are represented through language (Agren & van de Weijer, 2013; Bulthe, De Smedt & Op de Beeck, 2014; Butterworth et al., 2008; Carreiras et al., 2015; Castro et al., 2014; Dehaene et al., 2003; Gelman & Butterworth, 2005; Macizo et al., 2010; Nieder, 2005; Prior et al., 2015; Purpura & Reid, 2016; Semenza at al., 2006; Spelke & Tsivkin, 2001; Van Rinsveld et al., 2015; Zhang, 2016). On the other hand, in the context of the relation with representations of praxis, it is claimed that representations of numbers are rooted in bodily experiences, which is called the idea of embodied number representations (Domahs et al., 2010). Researchers point out that because – as children – we learn to count using our fingers, representations of numbers are related to representations of fingers (Andres, Olivier & Badets, 2008) or even representations of fingers serve as a scaffolding for representations of numbers (Brozzoli et al., 2008; Domahs, Krinzinger & Willmes, 2008; Kaufmann et al., 2008; Marghetis & Nunez, 2013; Nieder, 2005; Noel, 2005; Penner-Wilger et al., 2007; Riemer et al., 2016; Sato et al., 2007). This idea is supported by research results with subjects (mainly children) who suffer from finger agnosia (Noel, 2005; Penner-Wilger et al., 2007), and observation of the SNARC (*The spatial-numerical association of response codes*) effect, a phenomenon of representing numbers on a numerical axis, which reveals a strong relation between representations of numbers and spatial representations (Dehaene, Bossini, & Giraux, 1993).

It is worth adding that a very strong relation also exists between representations of praxis and representations of language themselves (Bidula & Kroliczak, 2015; Krefta et al., 2015; Kroliczak, Piper & Frey, 2011). All this makes one aware of the existence of strong and multidirectional interferences among representations of numbers, representations of language and representations of praxis (for a review on these topics, see Klichowski & Kroliczak, in press). These interferences are confirmed by numerous functional magnetic resonance imaging (fMRI) studies which show that during the processing of numbers brain areas linked to language and praxis are activated (Friedrich & Friederici, 2013; Nieder, 2016). The results of one of such studies are shown in Figure 1.

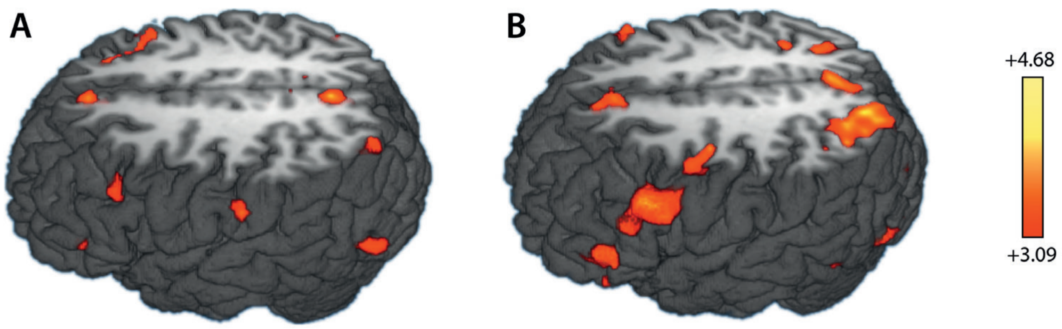

Fig. 1. Brain activations for mathematical stimuli

(A) Top left-lateral view of the functional activations 4 seconds after mathematical stimulus onset.
(B) Top left-lateral view of the functional activations 8 seconds after mathematical stimulus onset.

Source: Friedrich, R. M., & Friederici, A. D. (2013). Mathematical logic in the human brain: semantics. *PLoS ONE*, *8*(1). 1-10. doi: 10.1371/journal.pone.0053699. Figure 1 doi: 10.1371/journal.pone.0053699.g002. Under the terms of the Creative Commons Attribution License.

In the context of the relation between representations of numbers and representations of praxis, it has been founded that finger training increase young children's numerical performance. For instance, Gracia-Bafalluy & Noël (2008) have shown that stimulating young children with various finger games, e.g. a labyrinth game, a pointing game or a piano game, leads them to improve not only their finger or motor fitness, but also fosters children's numerical performance. The neural link between numbers and praxis is thus not only concerned with conditions for the processing of numbers, but also with the process of acquiring mathematical competences. From the perspective of cognitive neuroscience, finger training thus becomes an important element of the process of teaching young children maths. Cyberspace may become an excellent space for such training. Most often, young children have access to it through touchscreen tools (e.g. tablets or smartphones) – in other words, tools that make it possible to take part in various finger games via mobile apps (Klichowski et al., 2015; Przybyla, Basinska & Klichowski, 2014). To shed some light on this issue, we investigated mobile apps available for children and directed at finding examples of mobile apps that can increase children's numerical performance not through performing mathematical operations, but through finger training; in other words, apps that can be directed at young children (who do not perform mathematical operations yet). Sharing the example of this type of mobile apps can be useful for both parents and teachers of young children.

2. Methods

2.1. Procedure

Mobile apps in the App Store were used for the analysis. We searched for mobile apps that were indexed as mobile apps for mathematics for children (math apps). Then, we selected those that stimulate the child in a special way as far as finger training in concerned. In addition, we looked for mobile apps that had not been indexed as typical mobile apps for mathematics (non-math apps), but that we think stimulate finger training in such a way that they can improve young children's (children who do not perform mathematical operations yet) numerical performance (they involve activities such as a labyrinth game, a pointing game etc.).

2.2. Results

Selected mobile apps are shown in Table 1.

Table 1. Examples of mobile apps that can improve young children's numerical performance. Mobile apps indexed in the App Store as mobile apps for mathematics for children (math apps); mobile apps not indexed in the App Store as mobile apps for mathematics for children (non-math apps).

Math apps	Non-math apps
Wise Goat	Rock & Troll
PieQuest	Tappie Games
Math Puzzle	Hanoi
Inverto	BrainHQ
The Mesh	NeuroNation

2.2.1. Math apps

Wise Goat is an app aimed at young users of touchscreen devices who can already count objects, recognise numbers and associate them with the number of objects presented on the screen, add both numbers and objects, and both of these categories, as well as decide where fewer, more or the same number of objects are located, subtract, multiply and divide up to 100. The above-mentioned operations can be found in two main categories: „Automatic teacher – easy" and „Automatic teacher – difficult". A given category is selected by finger tapping. A sample screenshot from this app is shown in Figure 2.

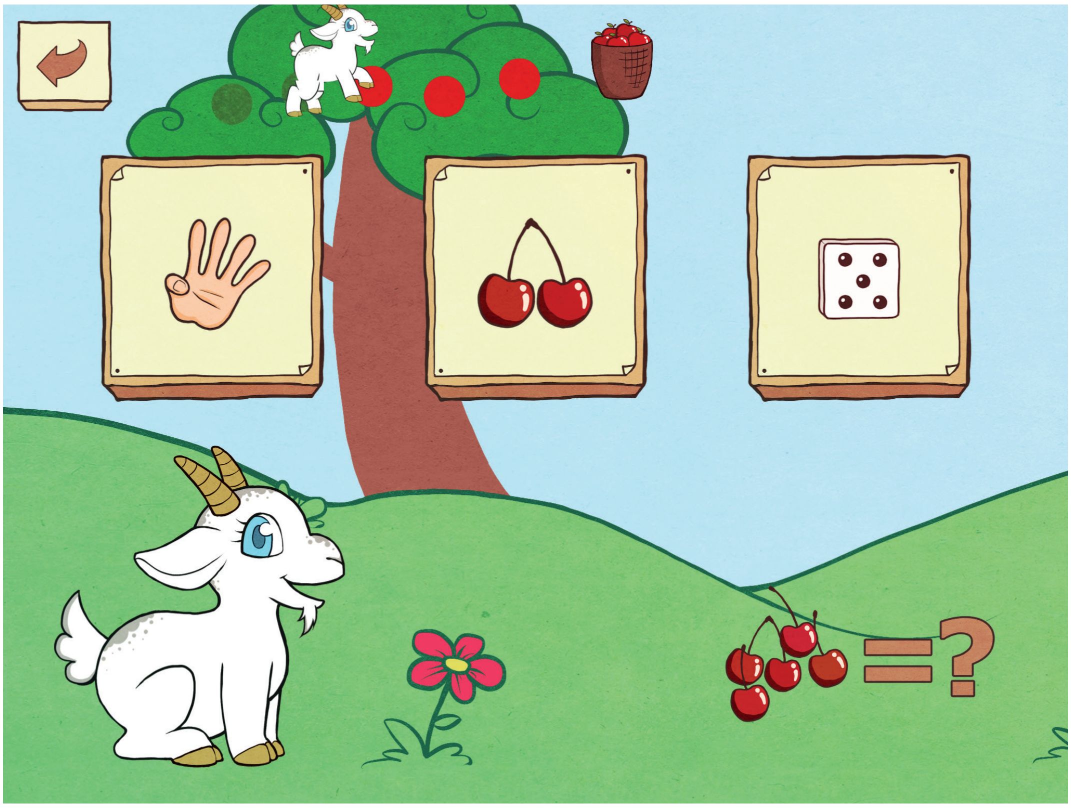

Fig. 2. Counting objects in Wise Goat

Source: own screenshot.

Apart from a user-friendly interface and nice background music, the app is also, or above all, very intuitive. The child watches the title Wise Goat walk across the screen when a task is performed well (when a series of tasks is completed, the Goat collects apples and then eats them, and the points scored allow the child the personalize the game). Any action taken by the user is performed by tapping a given field with their finger.

PieQuest is an application that combines two activities that children are well familiar with: performing calculations and doing a jigsaw. Particular fragments of a picture whose miniature is displayed for children in the top right-hand corner are uncovered when a task that conceals a given area of the puzzle is completed. A sample screenshot from this app is shown in Figure 3.

Fig. 3. Performing calculations and doing a jigsaw in PieQuest

Source: own screenshot.

After starting the application, a picture is displayed that makes it possible to choose one out of three categories: „Choose the operations" (operations related to adding, subtracting, multiplying and dividing); „Choose number of digits" (the numbers that we will use for the operations can have one, two, three or four digits); and „Choose number of puzzle pieces" (you can choose how many elements the puzzle is to have: 4, 9, 16 or 25). Depending on what we select, a screen is displayed with the corresponding operations. We tap on the one that we want to solve (action by tapping); an additional screen is displayed that shows a very simplified calculator. Our task is to use the numerical keypad (tap a given digit) and introduce the correct value of the task being solved, and then confirm and finish the calculation; then the picture will be uncovered.

The Math Puzzle application's subtitle is Training Your Brain Everyday. After tapping the Play button, the user can choose one of the four categories: „Basic math", „Kids count", „School math" and „Mathematician", and the selection influences what screen is displayed next by the application (acting by tapping appropriate fields). Time is counted while carrying out the tasks, and when answers are correct and quick, additional seconds are collected in the user's account. At the beginning, each category has one out of nine categories unblocked, and moving on to the next one is possible after solving the entire level well. A sample screenshot from this app is shown in Figure 4.

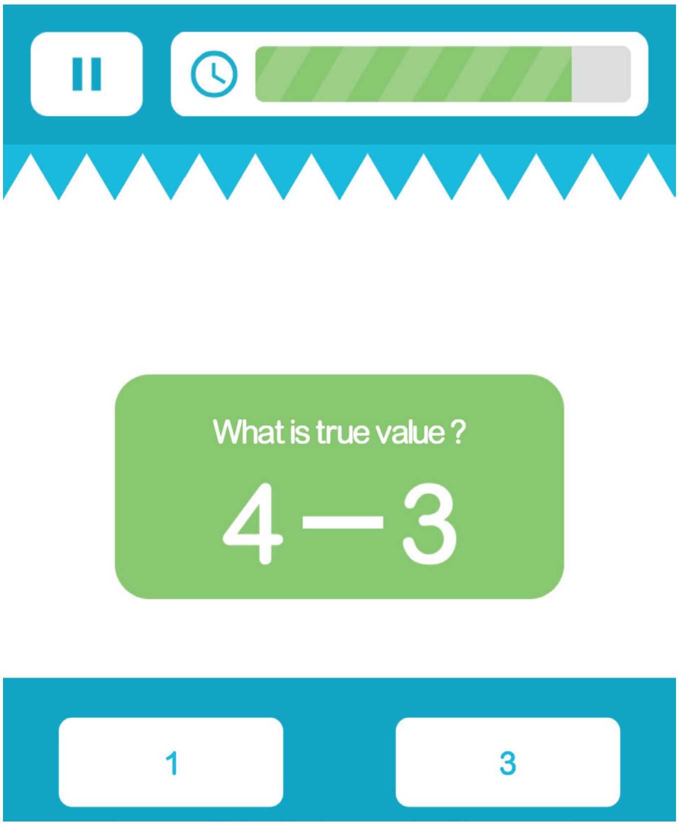

Fig. 4. Selecting the subtraction difference in Math Puzzle

Source: own screenshot.

Inverto is an application where the level cannot be selected; after tapping the Play button, the first game starts. It consists in tapping three digits (1, 2, 3) randomly spread on the screen in ascending order, in a given time (registered by a disappearing black bar in the top of the screen). A sample screenshot from this app is shown in Figure 5.

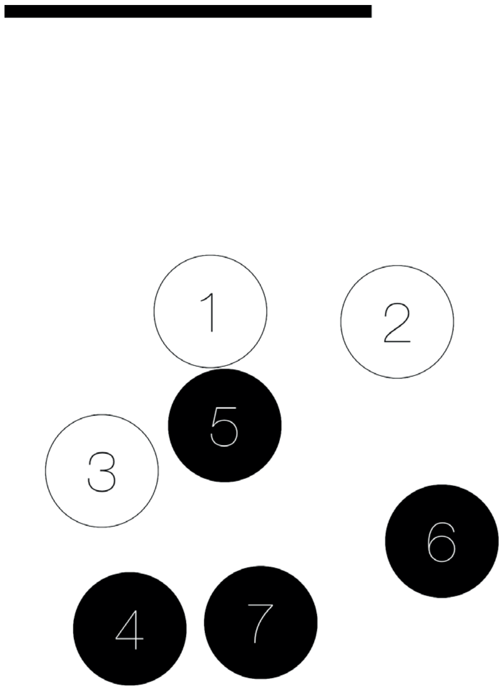

Fig. 5. Tapping digits in ascending order

Source: own screenshot.

Each new level begins automatically; there is no option to pause the game when it is in progress or when it has finished. The player has a short time limit to tap more and more digits; each completed level adds another digit to the new screen. Digits are displayed in ascending order, but located in a free way on the screen – finger movements have to be quicker and more precise if we want to move on to next levels. Hand movements are limited to the size of the touchscreen, yet the player can tap with one finger or use all fingers.

The Mesh is the most advanced application in the above category. It is prepared for older users; still primary school children (grades 1-3) will be able to use its first levels. In the game, once a level is completed, we become various animals: a rat, a dog, an ox etc. Each new level is characterised with more and more difficult mathematical calculations consisting in attempting at reaching the value presented in the middle of the screen (value on the white field). A sample screenshot from this app is shown in Figure 6.

Depending on the level of difficulty, the mathematical operations may involve adding, subtracting, multiplying or dividing. In order to perform them, the player needs to pay attention to the colours of the fields where these values are located. And so, in order to add two fields, they have to be of the same colour; in order to subtract, they have to be of two different colours; the colour

Fig. 6. Using the adding or subtracting of two elements to reach a value in the middle of the screen on a white field

Source: own screenshot.

of the field can be changed (by double-tapping in a given field, its colour will change, or by changing the type of operations, e.g. by changing multiplying to dividing and the other way round). Operations are performed by moving other elements of the game with one's finger(s) towards the central value and laying one over another in order to reach the required value. The game allows to use both hands and requires various finger movements on the entire board.

2.2.2. Non-math apps

After tapping the Rock & Troll icon, the application takes us to the first screen of the game. By using both hands, we can move a little „metal" ball in a wooden frame in order to place them in the indicated spots. In this screen, we can choose the level of difficulty (Easy) or go to next screens where next levels will additionally show up to choose from (Medium and Hard). A sample screenshot from this app is shown in Figure 7.

Fig. 7. Selecting the level of difficulty in the game in the Rock & Roll application
Source: own screenshot.

This game is perfect for exercises that improve the visual and auditory coordination and manual skills. The players chooses the level of difficulty and the screen they would like to play. They can use both hands at the same time or change hands; this depends on the player's preferences and his skills at steering with both hands at the same time.

Tappie Games is undoubtedly a game aimed at the youngest children; when tapping the app icon, a screen is displayed depicting a pair of small kids who use a tablet. Also, information about the potential age of the app users is displayed: „1+" is a text displayed next to those children in the cover. A sample screenshot from this app is shown in Figure 8.

The very description of the application in the App Store presents how it can be used: „A free and easy way to improve fingers' movement coordination for your child. Tappie Games arms parents with an interactive touch-screen application specially designed to develop the fine motor skills of small children aged 1 year and older. (…) The application challenges children by requiring progressively greater interaction with each new screen" (apple.com).

Fig. 8. Tap and jump: the third level of the Tappie Games game

Source: own screenshot.

In order to start a given board, it has to be unblocked; it is enough to slide one's finger following a trace on the screen, which resembles two overlaying screens. The one below is the actual board screen, but it has to be unblocked to reach it. Unblocking resembles a filter comprised of a steamed up pane of glass that someone touched with their finger and left a line trace. This is the „tunnel" that we have to slide along with our finger in order to unblock the game.

The above-mentioned four screens change as a result of performing the activities on the subsequent levels. For example, the first picture on the first level is a small river with a little frog. After tapping it with one's finger, it jumps on to the other bank. Level two for the same picture is different in that there are already two frogs; level three contains two frogs and a cricket etc. These changes involve each level and each of the four boards described.

The subtitle of the application called Tower of Hanoi already indicates the author's objective: Online Brain Training. After choosing the app icon, a menu screen is displayed where we can choose among a few fields (by tapping a given field with the finger), but three of them are most important for us: „Today`s Question", „Easy Practise", „Record/Integration". A sample screenshot from this app is shown in Figure 9.

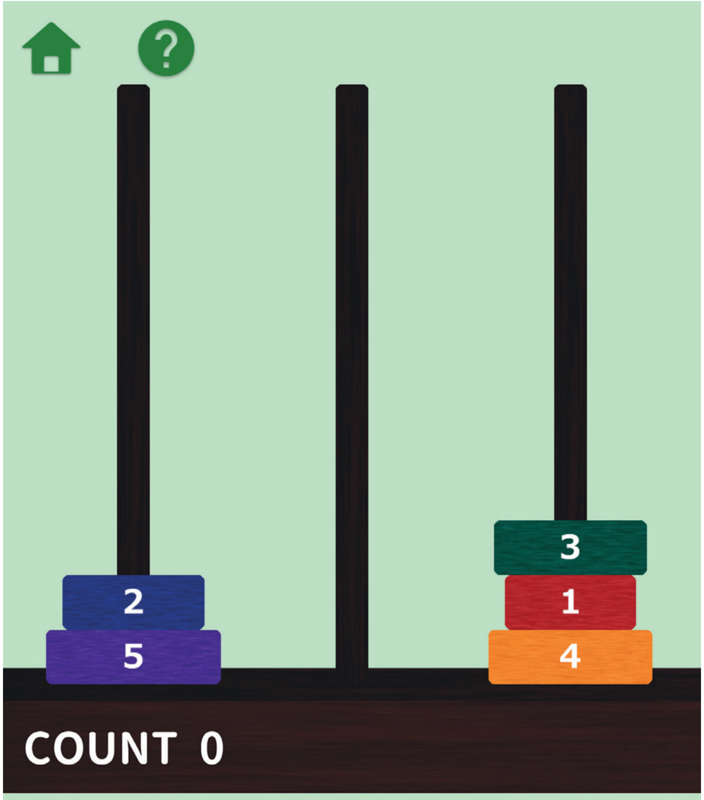

Fig. 9. Tower of Hanoi at the beginning of the game with 5 elements

Source: own screenshot.

The player's all movements are done by sliding their finger on the screen to move rings that build a tower. Actually, in order to play this type of game, there is no need for the player to know the digits assigned to a given ring; they can play with the rings based on their size only. To achieve the aim, it is undoubtedly necessary to be able to think logically and analyse the current and future movements. Playing involves taking some similar movements to move the rings between poles in order to queue them starting with the biggest one, and ending with the smallest one.

BrainHQ – Brain Training Exercises By Posit Science is a very advanced application. The description convinces the user that „BrainHQ is a brain training program that really works. It's built on the principles of »brain plasticity«„ and that „it is the only brain training program that has been shown to work in large-scale randomized clinical trials – the gold-standard for scientific results. BrainHQ's exercises have been tested in studies by researchers from leading institutions, including the Mayo Clinic, the University of California at Berkeley, and the Department of Veterans Affairs" (itunes.apple.com).

After tapping the application icon, the user needs to make a choice: „Create Account or Get Started". When describing the application, we will not focus on its advanced features, available for adult users, but on those that we think support this publication's thesis best. We choose „Get Started" and start with „Beginners Brain Challenge" which contains the following exercise: Eye for Detail. A sample screenshot from this app is shown in Figure 10.

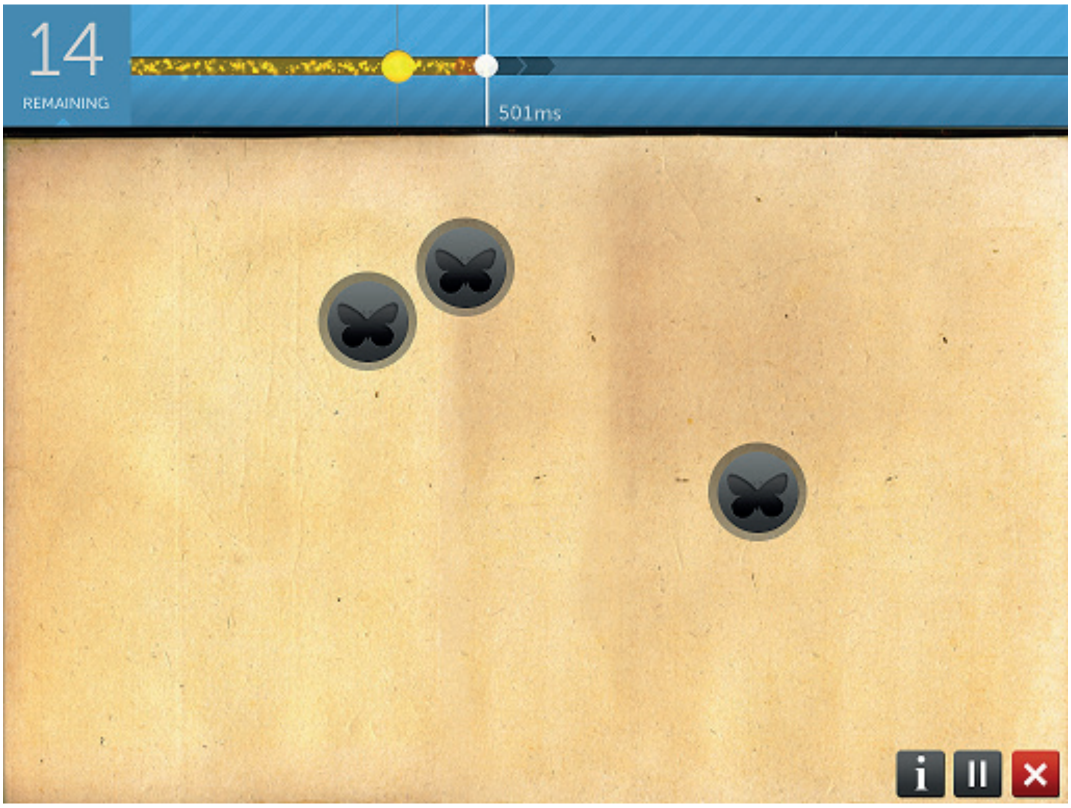

Fig. 10. The game board after butterflies have been displayed. The child's task is to tap pairs of identical butterflies

Source: own screenshot.

When the game starts, three butterflies are displayed on the screen, with information in the top part of the screen about how many exercises are still ahead (Remaining 18), and next to it, there is a bar that shows our reaction time. When the task is not completed well, the number of displays is reduced accordingly and the reaction time in milliseconds decreases, too. The more exercises we have completed and the shorter our reaction time, the quicker the butterflies are displayed and disappear from the screen.

Last but not least, we will describe the NeuroNation – Brain Training application. It is another application whose creators describe its features in the following way: „More than 7.000,000 members! (…) A recent study by the Free University of Berlin demonstrated the effectiveness of NeuroNation's brain training. All exercises were developed in cooperation with renowned neuroscientists and are based on state-of-the-art scientific research" (itunes.apple.com).

Due to the application's very complex structure and its big potential, we would like to focus only on „Single Exercises" and six tasks that are available (unblocked). These are: „Color Craze", „Chain Reaction", „Path Finder Reverse", „Path Finder", „Rotator", „Trail Tracker". Practically all of them support our thesis, so we decided to choose three to have a closer look at them (Figure 11).

Fig. 11. Training selection in the NeuroNation application

Source: own screenshot.

Path Finder Reverse consists in finding the way in reverse order (as opposed to the Path Finder game). The player's task is to watch the order in which points displayed on the screen are connected, and then tap them in reverse order (starting with the last one and ending with the first one). The number of elements and the number of taps both increase as the player's results get better (Figure 12).

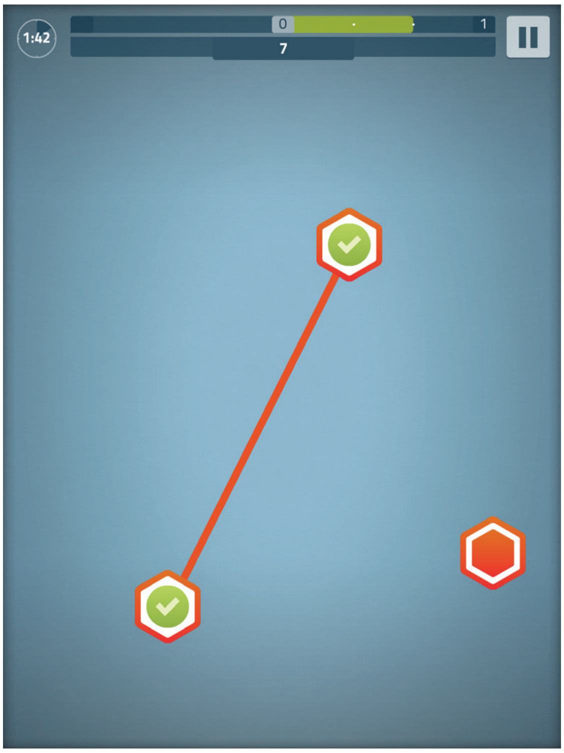

Fig. 12. Finding the way back in the tutorial

Source: own screenshot.

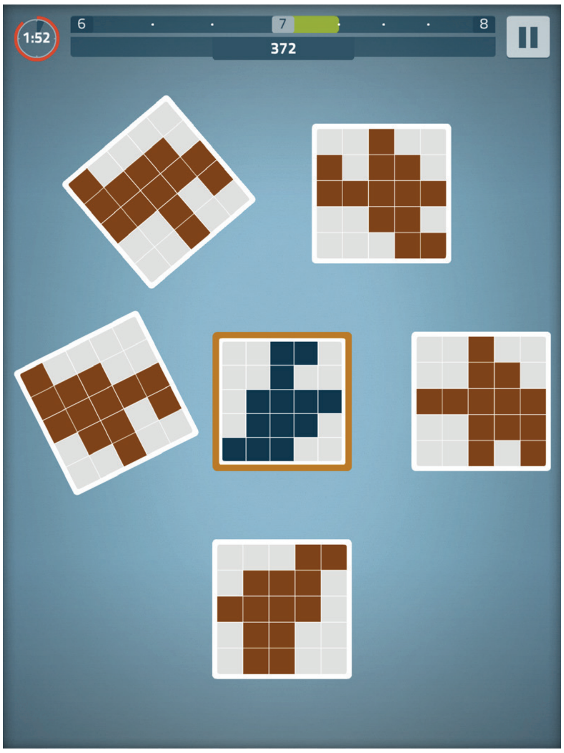

Fig. 13. Matching shapes to what is displayed in the centre the screen

Source: own screenshot.

Rotator is a game similar to Tetris. The difference is that here we do not match the falling shapes to free spacer in order to complete so-called lines. In this application, a shape is displayed surrounded with 5 other shapes that after a while start to rotate and change places. The player's task is to find a shape identical to the one displayed in the centre of the screen and tap on it. Of course, all this is performer within a time limit set by the game (Figure 13).

Trail Tracker consists in moving a symbol that resembles the cursor on a chequer board of 6 per 6 fields on touchscreens. The player's task is to guess where the object will be located as a consequence of reading pictograms (arrows) displayed in the top part of the screen. The player's task is not only to tap the field where the „cursor" should be located as a result of single steps, but to indicate straight away the target field where the „cursor" will land at the end (Figure 14).

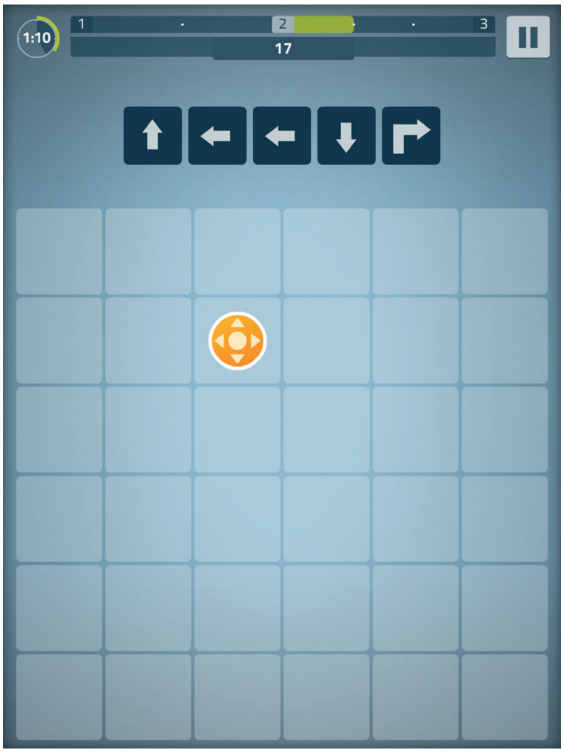

Fig. 14. Indicating the fields where an object is moved to on a chequer board

Source: own screenshot.

3. Discussion

This study shows that from the perspective of cognitive neuroscience, cyberspace may increase young children's (children who do not perform mathematical operations yet) numerical performance, because it offers young children access to various types of finger games in the form of mobile apps. This type of finger games, played on touchscreen tools such as tablets or smartphones, are a form of finger training, and because representations of fingers are linked to representations of numbers, this sort of finger training may increase young children's numerical performance.

It has to be underlined, however, that many studies of cognitive neuroscience show that tapping on a flat screen is an unnatural process and it negatively affects representations of fingers in the human brain. For instance, Gindrat et al. (2015) have shown that touchscreen tools use reorganized representation of the fingers in the somatosensory cortex in a way that leads to the development of chronic pain (see also: Berolo, Wells and Amick, 2011). What is more, a functional magnetic resonance imaging (fMRI) study of Loh and Kanai (2014) shows that intensive and simultaneous use of various ICT tools (e.g. tablet and smartphone) negatively affects the human brain. The researchers found that the higher the Media Multitasking Index (MMI) of individuals, the lower the gray matter density in the anterior cingulate cortex (ACC) of their brains (see Figure 15). The ACC is one of the most important areas responsible for information processing, which is why smaller gray matter volumes in the ACC lead to deterioration in learning and a general decrease in cognitive effectiveness.

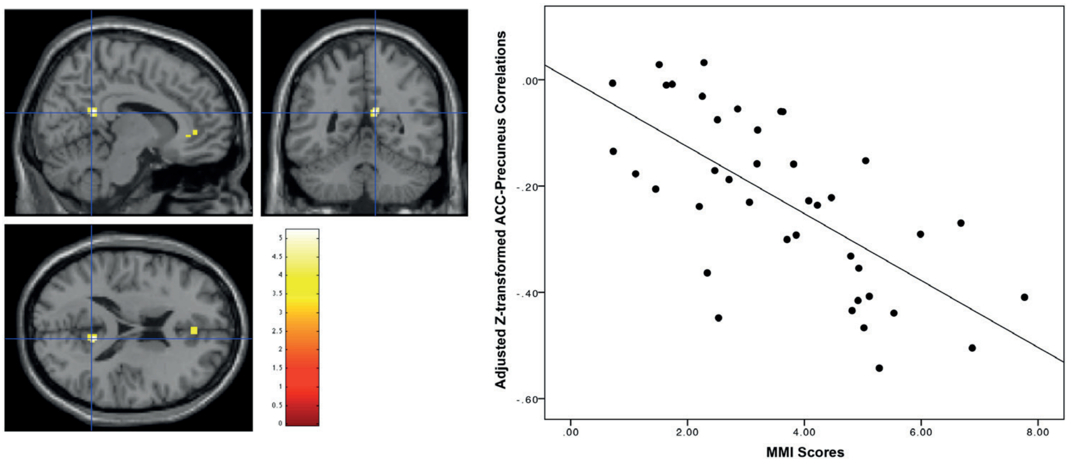

Fig. 15. Association between Media Multitasking Index (MMI) scores and gray matter density in the anterior cingulate cortex (ACC). Individuals with a higher MMI had smaller gray matter density in the ACC.

Source: Loh, K.K. and Kanai, R. (2014). Higher Media Multi-Tasking Activity Is Associated with Smaller Gray-Matter Density in the Anterior Cingulate Cortex. *PLoS ONE, 9*(9). 1-7. doi: 10.1371/journal.pone.0106698. Figure 2 doi: 10.1371/journal.pone.0106698.g002. Under the terms of the Creative Commons Attribution License.

All in all, cyberspace provides young children with easy access to various types of finger games that they can play with using a tablet or smartphone. These types of games are a form of finger training, and as such they should increase young children's numerical performance. However, a lot of data show that tapping on a flat screen of tablet or smartphone is a very unnatural process and can negatively affect human growth. A wide availability of various finger games for children in the form of mobile apps builds up some hopes as far as shaping mathematical competence in children is concerned, yet still thorough research is necessary to show whether touchscreen tools are indeed tools that are cognitively beneficial and can be used in finger training, not only among children, but also among all users.

4. Author contributions

This project was conceptualized by MK. Apps were collected and analysed by TP. The manuscript was written by MK and TP.

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REFERENCES

Agren, M. & van de Weijer, J. (2013). Number problems in monolingual and bilingual French-speaking children. *Language, Interaction and Acquisition, 4*(1). 25-50. doi: 10.1075/lia.4.1.02agr.

Andres, M., Olivier, E. & Badets, A., (2008). Actions, words, and numbers. A motor contribution to semantic processing?. *Current Directions in Psychological Science,* 17(5). 313-317. doi: 10.1111/j.1467-8721.2008.00597.x.

Berolo, S., Wells, R.P. & Amick, B.C. (2011). Musculoskeletal symptoms among mobile hand-held device users and their relationship to device use: a preliminary study in a Canadian university population. *Applied Ergonomics,* 42(2). 371-378. doi:10.1016/j.apergo.2010.08.010.

Bidula, S.P. & Kroliczak, G. (2015). Structural asymmetry of the insula is linked to the lateralization of gesture and language. *European Journal of Neuroscience*, 41(11). 1438-1447. doi: 10.1111/ejn.12888.

Blanco-Elorrieta, E. & Pylkkanen L. (2016). Composition of complex numbers: delineating the computational role of the left anterior temporal lobe. *NeuroImage. 124*. 194-203. doi: 10.1016/j.neuroimage.2015.08.049.

Brozzoli, C., Ishihara, M., Gobel, S.M., Salemme, R., Rossetti, Y. & Farne, A. (2008). Touch perception reveals the dominance of spatial over digital representation of numbers. *Proceedings of the National Academy of Sciences, 105*(14). 5644-5648. doi: 10.1073/pnas.0708414105.

Bulthe, J., De Smedt, B. & Op de Beeck, H.P. (2014). Format-dependent representations of symbolic and non-symbolic numbers in the human cortex as revealed by multi-voxel pattern analyses. *NeuroImage, 87*. 311-322. doi: 10.1016/j.neuroimage.2013.10.049.

Butterworth, B., Reeve, R., Reynolds, F. & Lloyd, D. (2008). Numerical thought with and without words: evidence from indigenous Australian children. *Proceedings of the National Academy of Sciences*, *105*(35). 13179-13184. doi: 10.1073/pnas.0806045105.

Carreiras, M., Monahan, P.J., Lizarazu, M., Dunabeitia, J.A. & Molinaro N. (2015). Numbers are not like words: different pathways for literacy and numeracy. *NeuroImage, 118*. 79-89. doi: 10.1016/j.neuroimage.2015.06.021.

Castro, A., Sumich, A., Premkumar, P. & Jones, G. (2014). How do incorrect results change the processing of arithmetic information? Evidence from a divided visual field experiment. *Laterality, 19*(3). 340-353. doi: 10.1080/1357650X.2013.826237.

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*, 122(3). 371-396. doi: 10.1037/0096-3445.122.3.371.

Dehaene, S., Piazza, M., Pinel, P. & Cohen, L. (2003). Three parietal circuits for number processing. *Cognitive neuropsychology, 20*(3-6). 487-506. doi: 10.1080/02643290244000239.

Domahs, F., Krinzinger, H. & Willmes, K. (2008). Mind the gap between both hands: evidence for internal finger-based number representations in children's mental calculation. *Cortex, 44*(4). 359-67. doi: 10.1016/j.cortex.2007.08.001.

Domahs, F., Moeller, K., Huber, S., Willmes, K. & Nuerk, H.-C. (2010). Embodied numerosity: implicit hand-based representations influence symbolic number processing across cultures. *Cognition, 116*(2). 251-266. doi: 10.1016/j.cognition.2010.05.007.

Friedrich, R. M., & Friederici, A. D. (2013). Mathematical logic in the human brain: semantics. *PLoS ONE*, *8*(1). 1-10. doi: 10.1371/journal.pone.0053699.

Gelman, R. & Butterworth, B. (2005). Number and language: how are they related?. *Trends in cognitive sciences*, *9*(1), 6-10. doi:10.1016/j.tics.2004.11.004.

Gindrat, A.-D., Chytiris, M., Balerna, M., Rouiller, E.M. & Ghosh, A. (2015). Use-dependent cortical processing from fingertips in touchscreen phone users. *Current Biology, 25*(1). 109-116. doi:10.1016/j.cub.2014.11.026.

Gracia-Bafalluy, M. & Noel, M.-P. (2008). Does finger training increase young children's numerical performance?. *Cortex, 44*(4). 368-375. doi:10.1016/j.cortex.2007.08.020.

Houde, O. & Tzourio-Mazoyer, N. (2003). Neural foundations of logical and mathematical cognition. *Nature Reviews Neuroscience, 4*. 507-514. doi: 10.1038/nrn1117.

Iversen, W., Nuerk, H.-C., Jager, L. & Willmes, K. (2006). The influence of an external symbol system on number parity representation, or what's odd about 6?. *Psychonomic Bulletin & Review, 13*(4). 730-736. doi: 10.3758/BF03193988.

Kaufmann, L., Vogel, S.E., Wood, G., Kremser, C., Schocke, M., Zimmerhackl, L.B. & Koten, J.W. (2008). A developmental fMRI study of nonsymbolic numerical and spatial processing. *Cortex*, *44*(4). 376-385. doi: 10.1016/j.cortex.2007.08.003.

Klichowski, M. & Kroliczak, G. (in press). Numbers and functional lateralization: a visual half-field and dichotic listening study in proficient bilinguals.

Klichowski, M., Bonanno, P., Jaskulska, S., Smaniotto Costa, C., de Lange, M. & Klauser, F.R. (2015). CyberParks as a new context for Smart Education: theoretical background, assumptions, and pre-service teachers' rating. *American Journal of Educational Research, 3(12A)*. 1-10. doi: 10.12691/education-3-12A-1.

Krefta, M., Michalowski, B., Kowalczyk, J. & Kroliczak, G. (2015). Co-lateralized bilingual mechanisms for reading in single and dual language contexts: evidence from visual half-field processing of action words in proficient bilinguals. *Frontiers in Psychology, 6*:1159. doi: 10.3389/fpsyg.2015.01159.

Kroliczak, G., Piper, B.J. & Frey, S.H. (2011). Atypical lateralization of language predicts cerebral asymmetries in parietal gesture representations. *Neuropsychologia, 49*(7). 1698-1702. doi: 10.1016/j.neuropsychologia.2011.02.044.

Loh, K.K. & Kanai, R. (2014). Higher Media Multi-Tasking Activity Is Associated with Smaller Gray-Matter Density in the Anterior Cingulate Cortex. *PLoS ONE, 9*(9). 1-7. doi: 10.1371/journal.pone.0106698.

Lyons, I.M., Ansari D. & Beilock, S.L. (2015). Qualitatively different coding of symbolic and nonsymbolic numbers in the human brain. *Human Brain Mapping. 36*(2). 475-488. doi: 10.1002/hbm.22641.

Macizo, P., Herrera, A., Paolieri, D. & Roman, P. (2010). Is there cross-language modulation when bilinguals process number words?. *Applied Psycholinguistics, 31*(4). 651-669. doi: 10.1017/S0142716410000184.

Marghetis, T., & Nunez, R. (2013). The motion behind the symbols: a vital role for dynamism in the conceptualization of limits and continuity in expert mathematics. *Topics in cognitive science*, *5*(2), 299-316. doi: 10.1111/tops.12013.

Nieder, A. (2005). Counting on neurons: the neurobiology of numerical competence. *Nature Reviews Neuroscience, 6*. 177-190. doi:10.1038/nrn1626.

Nieder, A. (2016). The neuronal code for number. *Nature Reviews Neuroscience*, *17*(6). 366-382. doi: 10.1038/nrn.2016.40.

Noel, M.-P. (2005). Finger gnosia: a predictor of numerical abilities in children?. *Child Neuropsychology, 11*(5). 413-430. doi: 10.1080/09297040590951550.

Penner-Wilger, M., Fast, L., LeFevre, J.A., Smith-Chant, B.L., Skwarchuk, S., Kamawar, D. & Bisanz, J. (2007). The foundations of numeracy: subitizing, finger gnosia, and fine-motor ability. *Proceedings of the 29th Annual Cognitive Science Society*. Austin, TX: Cognitive Science Society. 1385-1390.

Prior, A., Katz, M., Mahajna, I. & Rubinsten, O. (2015). Number word structure in first and second language influences arithmetic skills. *Frontiers in Psychology, 6:*266. doi: 10.3389/fpsyg.2015.00266.

Przybyla, T., Basinska, A. & Klichowski, M. (2014). Smartphones and children's mathematics. In H. Krauze-Sikorska, M. Klichowski & A. Basinsk (Eds.), *Children in the postmodern world. Culture – media – social inequality* (pp. 11-20). Poznan: Wydawnictwo Naukowe UAM.

Purpura, D.J. & Reid, E.E. (2016). Mathematics and language: individual and group differences in mathematical language skills in young children. *Early Childhood Research Quarterly, 36*. 259-268. doi: 10.1016/j.ecresq.2015.12.020.

Riemer, M., Diersch, N., Bublatzky, F. & Wolbers, T. (2016). Space, time, and numbers in the right posterior parietal cortex: differences between response code associations and congruency effects. *NeuroImage, 129*. 72-79. doi:10.1016/j.neuroimage.2016.01.030.

Sato, M., Cattaneo, L., Rizzolatti, G. & Gallese, V. (2007). Numbers within our hands: modulation of corticospinal excitability of hand muscles during numerical judgment. *Journal of Cognitive Neuroscience*, *19*(4). 684-693. doi: 10.1162/jocn.2007.19.4.684.

Semenza, C., Delazer, M., Bertella, L., Grana, A., Mori, I., Conti, F.M. & Mauro, A. (2006). Is math lateralised on the same side as language? Right hemisphere aphasia and mathematical abilities. *Neuroscience Letters, 406*(3), 285-288. doi: 10.1016/j.neulet.2006.07.063.

Spelke, E.S. & Tsivkin, S. (2001). Language and number: a bilingual training study. *Cognition*, *78*(1). 45-88. doi: 10.1016/S0010-0277(00)00108-6.
Van Rinsveld, A., Brunner, M., Landerl, K., Schiltz, C. & Ugen, S. (2015). The relation between language and arithmetic in bilinguals: insights from different stages of language acquisition. *Frontiers in Psychology, 6*:265. doi: 10.3389/fpsyg.2015.00265.
Zhang, X. (2016). Linking language, visual-spatial, and executive function skills to number competence in very young Chinese children. *Early Childhood Research Quarterly, 36*. 178-189. doi: 10.1016/j.ecresq.2015.12.010.

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