Learning Effects of Arithmetic Problem Solving while Unlocking a Mobile Phone

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This report evaluates the effects of using the mobile phone application "Unlock Your Brain" on arithmetic fact retrial. The application replaces the standard phone lock screen and requires users instead to solve a simple arithmetic problem to unlock the device for use. More than three million responses to addition problems were analysed and revealed that the users' problem-solving efficiency increases with number of performed unlocking actions.

In last two decades, several computer programs have been developed that aim to improve numerical competence and arithmetic skills (e.g. Naglieri & Johnson, 2000; Wilson, Dehaene, Dubios & Fayol, 2009; Käser et al. 2013). Recently, more and more educational software applications have appeared on the market that can be used on mobile devices such as smart-phones and tablet PCs. Most math assessments and training applications require the user to perform training sessions with multiple problems that last at least several minutes. We know that these blocked training programs, in which users are focused on processing several arithmetic problems, can be highly efficient and result in an improvement of mathematical skills (Naglieri & Johnson, 2000; Wilson, Dehaene, Dubios & Fayol, 2009; Käser et. al. 2013).

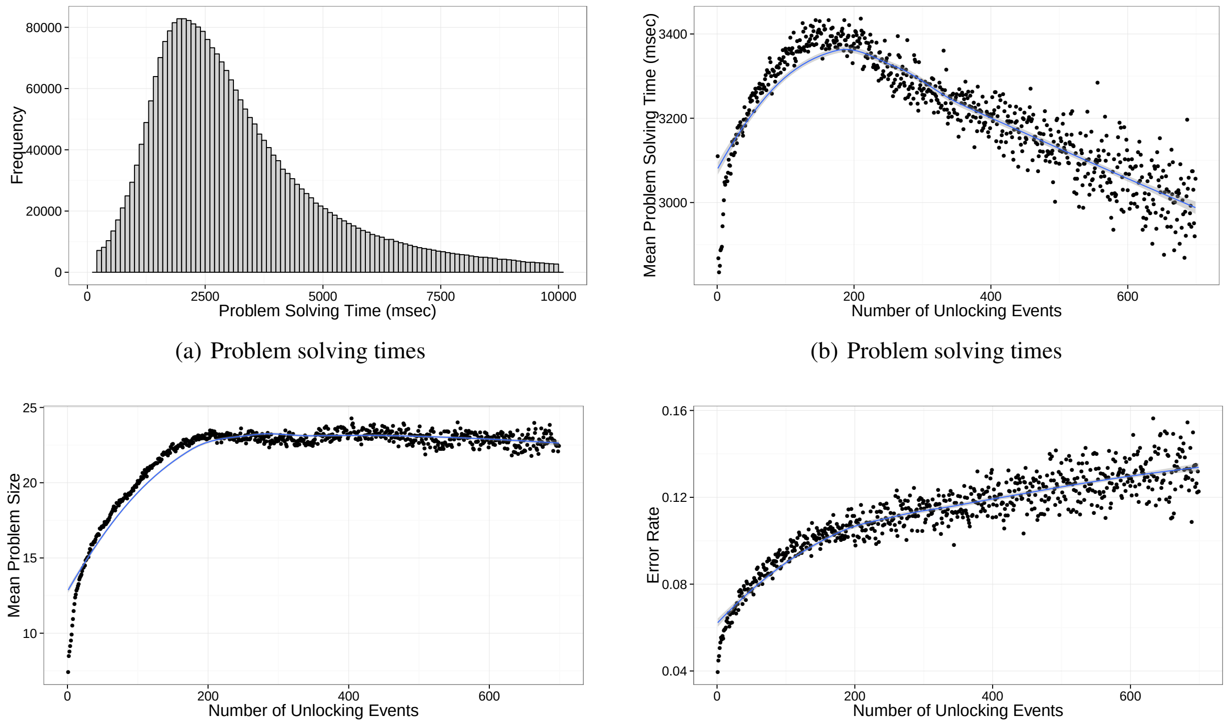
The most often mentioned disadvantage of these classical math programs consists in the fact that students have to allocate time and effort on a regular basis to perform the exercises. As an alternative to such "massed" practice, numerical competence might be trained in a "distributed" fashion, consisting in a procedure that confronts students with single arithmetic problems several times per day, so that practice occurs more incidentally. However, a distributed training that requires students to perform multiple micro-units of exercise throughout the day is difficult to realise and appropriate technical solutions for these purposes have so far been lacking.

Interestingly, the recently launched Android mobile phone application "Unlock Your Brain" (`http://www.unlockyourbrain.com`) follows this latter approach and offers a possibility to implement a distributed training of arithmetic fact knowledge. The Unlock Your Brain application replaces the standard lock screen of an Android mobile phone with a forced choice test of single arithmetic problems: Each time the user wants to use the mobile phone, a simple arithmetic problem is presented together with multiple numbers representing possible answers. To unlock the phone, the user has to solve the arithmetic problem and select the correct answer by dragging the corresponding number to the middle of the screen.

Importantly, the Unlock Your Brain application is implemented as an adaptive training environment. That is, the average difficulty of the presented problems depends on the user's recent performance. If a specific user repeatedly solves the problems within a predefined target time (typically 3 seconds), the average problem size for the subsequent unlock screens will be increased by the application. Conversely, if a user repeatedly fails to solve the problems correctly within the target time, problem size decreases.

Figure 1. Examples of the "Unlock Your Brain" lock screen

The application also offers the possibility to skip problems in order to unlock the phone. Nevertheless, since most people interact with their personal smart-phones very frequently throughout the day (Falaki et al., 2010), the lock screen replacement ensures that users are exposed to several arithmetic problems every day. As the collected data about the usage of this Unlock Your Brain application show, the vast majority of users indeed process the arithmetic problems on a regular basis and try to solve more than 80% of the presented problems (skip rate of 19.4%).



(a) Problem solving times (b) Problem solving times

(c) Problem size (d) Error rates

Figure 2. Distribution of the problem solving times (a) and the problem solving times (b), the problem size (c) and the error rates (d) as a function of the number of unlock events.

From a psychological and didactic point view, however, it has to be emphasized that there is so far no empirical evidence that such a distributed incidental problem solving activity that is instrumental to unlock a mobile phone results in an improvement of arithmetic fact retrieval. The current report therefore aims to provide an analysis of the user response data of the Unlock You Brain application and tests whether its extended use affects their performance in solving simple addition problems.

Method

Subjects

Users who indicated being younger than 18 years at the first day of data collection as well as users who did not use the application on a regular basis and solved fewer than 100 addition problems were excluded from the analyses. As a result, data from 13,285 participants were investigated. Users were not required to report personal details such as age or gender to register the application. Nevertheless, this information was available for 3,299 participants (24.8%) who used the possibility to register with their Facebook account details. We established that 26.3% of the participants in this subsample were female and that the average age was 28.6 years (SD=10.6).

Data selection

Only data collected between 15 February and 11 June 2013 from the Unlock Your Brain application version 122 or later were analysed. Responses from the training mode of the application were omitted. That is, we considered only problems that were processed to unlock the mobile phone.

To evaluate possible learning effects, only problem solving times and error rates from single- and two-digit addition problems were analysed. Skipped problems (19.4%), responses slower than 10,000 ms (8.08%) and responses faster than 200 ms (0.82%) were excluded. The data that finally entered the performance analyses comprised in total 3,041,472 responses to addition problems.

Results

The distribution of sample sizes across the different trials demonstrates a rather constant sample size for the first 100 trials. This reflects the simple fact that all subjects that did not use the application for this minimum amount of times were excluded from the analyses.

Figure 2a depicts the distribution of problem solving times for correct answers. The problems were solved on average within 3,210 ms (SD=1854). This mean response time reflects the fact that in 68.65% of the trials, the application settings were unchanged and the target problem solving time was set to the default value of 3,000 ms.

Figure 2b depicts the mean problem solving times as a function of the number of unlock events, that is, the number of processed problems. The average problem solving time first increases and peaks between the 180th and 200th unlock event. Afterwards, a clear continuous improvement in the response latencies can be observed. Interestingly, the development of the problem size describes at the same time a logarithmic function with very rapid increase for the first 180 to 200 unlock events (see Figure 2c). The average problem size remains rather constant afterwards.

The strong inverse relation between solving times and problem sizes for the first 200 trials is the result of the adaptive problem selection mechanism of the Unlock Your Brain application. As a consequence, is it highly problematic to use these two parameters in isolation as valid indicators for the users' arithmetic performance.

The same holds true for the error rates: Every problem that was not correctly solved with the first response was treated as erroneous response. As Figure 2d shows, the error rates increase with the number of unlocking events. Taking into account that error rates are correlated with problem difficulty, which is in turn increasing with number of unlock events (see Figure 2c), this trend is not surprising and would even be expected under the assumption that a continuous improvement in arithmetic performance takes places when using the application. The error rates do therefore also not represent a valid parameter for the evaluation of learning success in the adaptive training environment of Unlock Your Brain application.

Problem Solving Efficiency

The analysis of the overall performance in the problem solving task requires a parameter that considers both problem size and problem solving times. We calculated therefore for each unlock event the ratio between the problem size and the problem solving time in seconds (i.e., size per seconds). The resulting parameter can be interpreted as a score for the problem solving efficiency (PSE) and provides an appropriate measurement of arithmetic performance without the confound resulting from the adaptive problem selection.

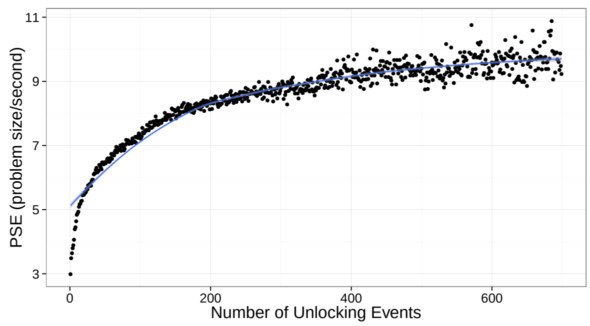


Figure 3. Problem solving efficiency (PSE) as a function of the number of unlocking events

As Figure 3 clearly depicts, problem solving efficiency increases with the number of unlock events. The logarithmically shaped learning curve is typical for any type of training study and suggests a continuous improvement in performance over the whole range of the investigated unlock events.

Statistics

The logarithmic development of the PSE scores was also shown by regression models of the averaged as well as individual PSE scores. A regression analysis of the mean PSE scores revealed the best-fitting logarithmic function $PSE = 3.40 * event^{0.16}$, $R^2 = 0.96$. The linear regression between PSE scores and unlock events explained clearly less variance in the data, $PSE = 6.80 + 0.005 * event$, $R^2 = 0.73$.

This very good logarithmic fit was confirmed by a linear mixed effect model of the individual data. We applied the model on the Log PSE scores with the Log Event Number as fixed-effect factor and Participant Number as random-effect factor. The model predicted the observed individual values very well, $R^2 = 0.45$. Importantly, the factor Event Number had a highly significant influence on the PSE score, $t = 511.00$, $p < 0.001$.

Discussion

This analysis of the Unlock Your Brain user response data demonstrates that the participants' performance to unlock a mobile phone by indicating the result of a one- or two-digit addition problem increases continuously over time. The problem-solving efficiency scores of over 13,000 subjects showed a typically-shaped logarithmic learning curve with a very strong improvement in performance for the first 200 processed problems.

Interestingly, the development of problems size together with problem solving times and error rates revealed two phases in the application's use: For the first 200 unlock events, the application increased the problem difficulties continuously, and this was accompanied by the cost of longer response times and higher error rates. In this period, the users presumably familiarised themselves with the interface of the Unlock Your Brain application. The pattern of effects in the data suggests moreover that the first phase is characterised by an adaptation process and an adjustment of problem difficulty appropriate for the individual user. Due to the increasing error rates, the adaptive problem selection algorithm limited the further growth of the problem size for the later unlock events. However, with a rather constant problem difficulty in the second phase of use, the users still benefited from their practice and arithmetic performances further improved continuously with respect to both problem-solving times and problem-solving efficiency scores (see Figure 2b and Figure 3).

The current evaluation of the Unlock Your Brain application demonstrates that the processing of simple addition problems to unlock a mobile phone has positive effects on the retrieval of arithmetic facts. This observation suggests that a distributed incidental practice of arithmetic tasks might be considered as an alternative to conventional massed learning environments to improve numerical competencies. As the Unlock Your Brain application nicely demonstrates, an interesting approach to implement a distributed training system is to modify mobile phone unlock screens and to exploit the many instances of phone unlocking actions throughout each day. At least for mobile phone affine subjects, this technology might be a promising tool for training of specific cognitive skills. The question whether distributed learning systems in mobile phone applications have also practical gains in teaching or for the treatment of severe math difficulties is an open questions that requires future research. However, the current finding of positive effects on arithmetic fact retrieval emphasizes the benefits of such technologies and might stimulate the development of new applications that use distributed learning for more systematic and individualised training.

References

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