Merobrixx – Mental Rotation Bricks: A Serious Game for Cognitive Training

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Abstract

In this paper we introduce the prototype of a cognitive training environment called "Merobrixx". Merobrixx is a serious game for players of all ages, including children and elderly people, based on traditional mental rotation training methods. Players interact with the game by means of a Tangible User Interface (TUI), which consists of three-dimensional objects made of LEGO bricks. A first evaluation of the system confirms that the user's performance in the game is positively related to his or her general mental rotation ability. Based on these findings further research regarding the conditions for a long term training effect is planned.

1 Motivation

With the Merobrixx system, we developed a *serious game* by combining the motivational aspects of a digital game with a serious mental skills training environment. A serious game is a type of videogame whose primary purpose goes beyond pure entertainment by e.g. teaching knowledge or training skills. An advantage of serious games compared to conventional forms of education is the higher intrinsic motivation to use the system (Prensky 2003) and a positive emotional experience (Gee 2007, Bormann et al. 2008). Despite the considerable amount and variety of available serious games, only a few studies have been conducted to measure the games' degree of efficiency in achieving the implied added value beyond the entertainment (Kato 2010). Merobrixx uses a Tangible User Interface (TUI) to allow users to naturally interact with the system as means to improve the access of the game for casual gamers. Merobrixx's TUI consists of several different three-dimensional geometrical objects. The presentation of real world objects should enrich the interaction experience and the manipulation task of the user (Ishii 2008). Thereby, the transformation of the real objects into virtual objects should be easier to understand and more direct than the more abstract forms of human-system-interaction like a joystick, a mouse or a complex gamepad. Furthermore, the inhibition threshold of less experienced users (e.g. casual gamers) should be lower than the threshold of a traditional interface (Jung et al. 2005). Besides affecting the game design, the geometric forms should also increase the training effect of the environment by controlling the virtual forms manually with real world forms. Therefore Merobrixx uses a manual training approach for the mental rotation skill incorporated in a virtual training environment.

2 Related Work

The ability to mentally rotate objects is a cognitive process which allows humans to mentally rotate two- or three-dimensional objects in order to recognize similar forms. This skill is known to be essential for orientation, movement and handling objects (cf. Valentijn et al. 2005; Peters et al. 2006). Although it is possible to train the mental rotation skill (Wexler et al. 1998), several problems have to be addressed in mental rotation training: Wiedenbauer (2007) indicated that it might take a long time until improvements occur. To avoid frustration, the environment and the motivation of the training is important.

To create such a training environment which motivates the user and trains spatial cognitive skills, Merobrixx takes the results of Wiedenbauer and Samsudin and Ismail (2004) into account and extends their idea of motivating training through the inclusion of game elements.

3 Merobrixx - the Game

In order to create an entertaining game with the ability to train mental rotation skills we used the concept of the Chinese puzzle game Tangram as a base. We extended the normal tangram game with additional rules about interactive and modern concepts. At first, we transferred the geometric forms of the tangram game into three-dimensional objects to generate an appropriate TUI for our game. The player's task within the game is to rebuild a displayed picture with the three-dimensional objects as fast as possible. The player's task within the game is to compare different displayed pictures with the three-dimensional objects as fast as possible. Figure 1 shows an example of the Merobrixx brick objects which are made of LEGO bricks. The construction of the bricks follows certain rules to make sure that each object has a similar format and complexity. Also, the resulting objects are similar to those used in the psychological MRT-A test (Peters et al. 1995), which is a standard test of mental rotation performance.

To use the brick objects as a TUI for our training environment it is necessary to track their position and rotation in space. Each brick object has a fiducial marker on each side which can be tracked by a normal webcam. A LC display is placed flat onto a table to act as an interactive game board. The markers of the brick objects are tracked by a standard webcam positioned on top of a mechanical arm. With the camera above the game board registering the brick the user placed on the board, we can display the tracked brick object's silhouette on the board - like holding the brick object under a lamp. This setup should make it easy for the users to understand the visual tracking mechanism, the purpose of the markers and thereby the overall concept of the game itself. When the user starts the game a target silhouette of a brick object is displayed on the screen. The user's objective is to find the right combination of brick objects which together would cast the shown silhouette (figure 1 shows an example of the target silhouette in this mode). The camera tracks the upside marker of each brick object and provides the direct feedback about his choice. Due to the six different silhouettes of each brick object and the interaction of two or more brick objects the level of complexity is scalable.

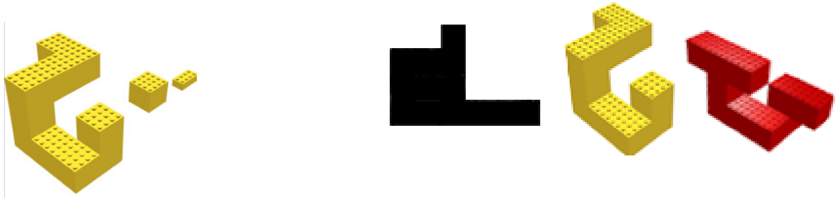

Figure 1: Example of a Merobrixx object (l), example task (r): Which of the two objects on the right would cast the shadow on the left?

A prerequisite to deploy a game as a training tool is that it's use involves those psychological processes which are intended to be trained. In the case of Merobrixx, the process in question is the ability to mentally rotate objects in 3D space. Stransky and colleagues for example have shown that performance in this task is variable between individuals and that the underlying cognitive process can in fact be trained: The effect of the training of the ability to rotate objects in three-dimensional space was still evident after one week, and seemed to be transferable to other tasks, too (Stransky et al. 2010). To evaluate the training possibilities of Merobrixx, we implemented a reduced evaluation mode into the game in which only one shadow of on brick object is displayed at a time. In this mode, the player's task is to find the right brick objects which fit to the displayed shadow in time. This allowed us to conduct an evaluation study early in the development process to assess if it is feasible to use Merobrixx as a game to train it's users in the mental rotation of objects in three dimensional space.

4 An Early Evaluation

We conducted a laboratory experiment in which scores in Merobrixx as well as performance in a standardized test of mental rotation skills were assessed. It was hypothesized that the Merobrixx score should be positively related to the test score. Also, to use a game as a training tool, it seems necessary that game difficulty can be adjusted to the user's needs (Ahissar

& Hochstein 1997). Therefore it was also tested if the difficulty of Merobrixx could be varied by allowing or disallowing the user to physically rotate the objects before deciding how the object has to be rotated to solve the task. Although the physical rotation process is supposed to be based on the mental rotation process, the possibility to manually rotate the object at least into a more favourable position before mentally rotating the object should make the task easier. Thus it was hypothesized that users should perform better in Merobrixx when they were allowed to manually rotate brick objects compared to when they were forced to mentally rotate the objects before touching them. Twenty-four healthy adults participated in this experiment (mean age: 26.21 years, *SD*=8.53 years, 12 male). Participants were sitting in front of the Merobrixx game board and played 42 rounds in evaluation mode. In each round, they were shown a shadow of a Merobrixx brick object on the game board (fig. 2, left side). The participant's task was to decide which of four brick objects (placed next to the game board) was the object whose shadow was shown, and to place it in correct orientation on the game board. Each round had to be completed within 15 seconds. The percentage of correct answers given within time was registered.

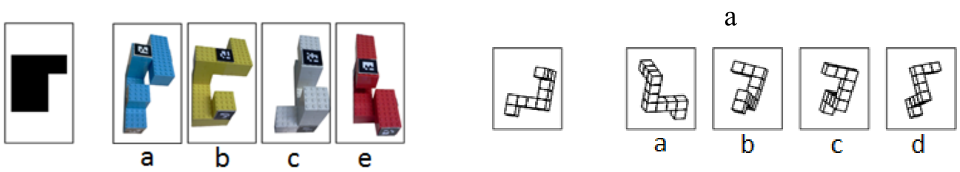

Figure 2: Tasks in Merobrixx (left) and MRT-A (right): Which of the objects on the respective right side casts the shadow (Merobrixx)/is identical to the object (MRT-A) on the left? (Answers: b for Merobrixx, a and c for MRT-A).

Each participant also filled out version A of the Redrawn Mental Rotation Test (MRT-A; Peters et al. 1995, cf. fig. 2, right side); by registering how many tasks in the MRT-A the participants started to solve the percentage of the participant's correct answers was computed. The order of playing Merobrixx and filling out the MRT-A was balanced. Thirteen of the players were allowed to physically rotate the objects while trying to find an answer to the Merobrixx tasks, the remaining players had to mentally rotate the objects.
The two groups of participants did not differ with respect to age ($t(22) = -.27$; $p = .77$), gender ($x^2(1) = .168$, $p = .68$) or score in the MRT-A ($t(22) = 1.45$, $p = .16$). The participant's mean percentage of correct answers in the MRT-A was 67.66% (*SD* = 15.78%), while they solved an average of 51.74% (*SD* = 12.59%) of the Merobrixx tasks. We found a significant positive relationship between the percentage of correct answers in Merobrixx and the percentage of corrects answers in the MRT-A, $r = .46$, $p < .05$. An ANCOVA of the participant's percentage of correct answers in Merobrixx with the participant's percentage of correct answers in the MRT-A as covariate revealed that the covariate was significantly related to the Merobrixx score, $F(1,19) = 7.83$, $p < .05$, $r = .54$. The sequence of Merobrixx and MRT-A did not play a significant role ($F(1,19) = .30$, $p = .59$, partial $\eta^2 = .06$). The effect of the type of rotation allowed on the Merobrixx score failed to reach a significant level ($F(1,19) = 3.91$, p (two-tailed) = .06, partial $\eta^2 = .171$).

Player's performance is obviously influenced by his or her ability to mentally rotate objects in three-dimensional space as the relationship between the Merobrixx score and the performance score in the established MRT test shows. The fact that this relationship is of moderate size (Cohen 1988) is understandable: Although successfully playing Merobrixx seems to rely on mental rotation skills, the game is in many other aspects not comparable to a standardized psychological test. The relationship found between performance in Merobrixx and mental rotation performance is a necessary prerequisite to further investigate if Merobrixx can be used as a tool to train users in their ability to mentally rotate objects. Further studies must show if indeed a learning effect can be found and if this learning might be transferable to domains other than finding the correct brick object to a projected silhouette. With respect to Merobrixx's game design, on a first glimpse it does not help to allow or disallow players to touch the brick objects before they have decided which object is the correct answer to the given task as this did not make a significant difference in the user's performance. However, the effect of this modification of the gameplay only just so failed to reach statistical significance and its effect size is moderate (Cohen 1965). Therefore it still seems promising to look into the use of aspects of the tangible interface for balancing the game. Furthermore, other aspects of Merobrixx gameplay (e.g. time to complete a round) could be modified to alter its difficulty to ensure that players are sufficiently challenged.

5 Future Work on the System

For the future, the system setup and the game itself should be updated to enhance the system structure and training ability. The tracking method of the system should be updated in further versions. Due to the dependence of the visual tracking on the environmental settings, the forms will feature build-in sensors, which measure the position and rotation. With this method we plan to improve the flexibility and accuracy of the system. In addition, the system setup will get smaller and less unnatural, because we can exclude the mechanical arm with the camera. Also, graphics and game mechanics should be improved as the goal of the early prototype was to prove the general use of spatial cognitive skills during the game. In further experiments, the long-term training ability of the system should be evaluated.

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