Comparison Between the Effects of Continuous and non-Continuous Visual Feedback on Motor Learning While Playing a Muscle-Controlled Serious Game

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Abstract: The guidance hypothesis suggests that continuous feedback during learning may lead to feedback dependency, with errors decreasing when feedback is provided and increasing when it is removed. This study investigates the effect of continuous (CVF) versus non-continuous visual feedback (NCVF) on motor learning using a muscle- controlled serious game. Subjects played the game for three consecutive days, with each day consisting of seven training sets and one learning control set without feedback. One group received CVF during training, while the other received NCVF. To assess transferability, the results of the learning control sets were compared between groups. Time to success during training decreased for CVF, and average time to reach the longest correct time period in the learning control set was higher for CVF compared to NCVF. The number of missed goals decreased for CVF, aligning with the expected positive impact of continuous feedback during training. However, the results for the learning control sets were inconclusive. While CVF showed a potential dependency on feedback, the decrease in missed goals indicates improved motor learning. More test days and subjects are required to confirm the findings and draw definitive conclusions regarding the guidance hypothesis.

1 INTRODUCTION

Learning a new motor task can be difficult, especially the learning of fine motor movements can be challenging. The guidance hypothesis predicts that the guiding properties of extended feedback are positive for motor learning when used to decrease errors during the task but can also lead to a dependency on this feedback (Winstein, Pohl, & Lewthwaite, 1994, Fuchs, Knauer, & Friedrich, 2018). Therefore, a highly directive form of feedback could be detrimental to learning. Furthermore, the guidance hypothesis expects that practicing with a high relative frequency of reinforced feedback will have a negative effect on learning. (Winstein, Pohl und Lewthwaite 1994).

There are still controversies about the guidance hypothesis today (McKay, et al. 2022). Sülzenbrück & Heuer conducted a study in which subjects had to move a courser, receiving either continuous feedback or terminal feedback. During the task, the group that received continuous feedback achieved better results for the end position of the cursor. After practicing with one of the feedback methods, subjects had to perform the movement without feedback. The group with terminal visual feedback achieved better results compared to the group receiving continuous visual feedback. (Sülzenbrück und Heuer, 2011)

Another study of Marco-Ahulló et al. investigated the effect of different visual feedback frequencies during a balance task on performance of a post-test without feedback. Results presented in this study show that reduced feedback is more effective at learning a postural task than continuous feedback. (Marco- Ahulló, et al. 2024) An increased performance in arm movements by using less feedback compared to 100% feedback was shown in a study of Suvillian, Kantak and Burtner as well.

On the other hand, a conducted study of Goodwin achieved better results in stability while performing a balance task after practicing with concurrent feedback compared to less feedback (Goodwin 2019). A study investigating the acceleration of shoulder

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flexions achieved equal or surpass results with concurrent visual feedback compared to terminal feedback (Yamamoto und Ohashi 2014). Results of the study from Wulf, Shea and Matschiner provide support for the notion that higher feedback frequencies are beneficial for the learning of a complex motor skill. Subjects had to perform a virtual slalom skiing task. Their findings suggests that there may be an interaction between task difficulty and feedback frequency. (Wulf, Shea und Matschiner 1998)

The current state of the art shows, that there are still controverses according continuous and non-continuous visual feedback in motor learning. Improving motor skills can be beneficial for rehabilitation, sport, or daily living situations. Therefore, the investigation of the different feedback methods is important. For this reason, the aim of this study is to investigate continuous and non-continuous visual feedback on learning the precise control of muscle activity with a muscle controlled serious game in a training and a learning control scenario.

2 METHODS

2.1 Participants

In the experiment 12 healthy subjects (7 males and 5 females; average age 27 ±4) voluntarily participated. All subjects were righthanded in accordance to the Edinburgh handedness inventory (Oldfield 1971). Subjects gave their written informed consent to the experiment and were told that they were allowed to stop the experiment at any time without any consequences. Subjects were divided in two groups consisting of six subjects each. One group received continuous visual feedback and the other group received non-continuous visual feedback. The group selection was randomized.

2.2 Data Acquisition

The following descriptions of the serious game and the experimental set-up is an adapted version of an (Habenicht and Kirchner 2024). The difference between the previous paper is non-continuous visual feedback which was substituted with the before used auditory feedback.

Electromyography (EMG)

For measuring muscle activity, subjects were prepared with surface EMG electrodes before the experiment started. A bipolar 16 channel EMG system from Cometa was used. After skin preparation, which included the cleaning with alcohol, the electrodes were placed on the m. flexor digitorum. The placement was based on the SENIAM guidelines (Hermens, et al. 2000). to ensure that the electrode is in the same position for each measurement, the electrode position was documented with photos.

2.2.1 Serious Game

Serious games are games, which aren't there just for fun but also to have positive effects on the player (Olgers, de Weg and Ter Maaten 2021). The serious game consists of a column divided into four areas (Figure 1). These areas can be reached by a bar, which is controlled by the contraction of the *m. flexor digitorum* muscle. this muscle was used because it is considered easy to use. Since all muscles are activated in the same way, it should be possible to draw conclusions about the possible behavior of the other muscles. Next to the areas the digits 0,1,5, and 10 are shown. The aim of the game is to reach the areas of the digit (1,5, and 10) displayed in randomized order as accurately as possible with the muscle-controlled bar. The digit to be reached is clearly displayed above the column. The bar must be in the range of the displayed digit for at least three seconds. As soon as the bar is in the correct range, a countdown of three seconds appears After the three seconds in the goal area the bar must be steered into the 0 range by relaxing the muscle. After another three seconds in this area, the next digit to be reached will be displayed. The next goal to reach will only appear, when the one before was successfully reached.

The group that receives continuous visual feedback (CVF) can see the moving bar and its current position all the time.

The group with non-continuous visual feedback (NCVF) can only see the bar when it is in the correct area of the column. When the bar is outside of the area of the goal, it will not be displayed.

Before playing, the game had to be calibrated. We used the maximum muscle activity. The average of a five-second maximum muscle contraction (MVC) was calculated. The areas of the column were defined based on the average MVC value. The MVC value represents 100%. A detailed description of which number corresponds to which muscle activity relative to MVC can be seen in Table 1.

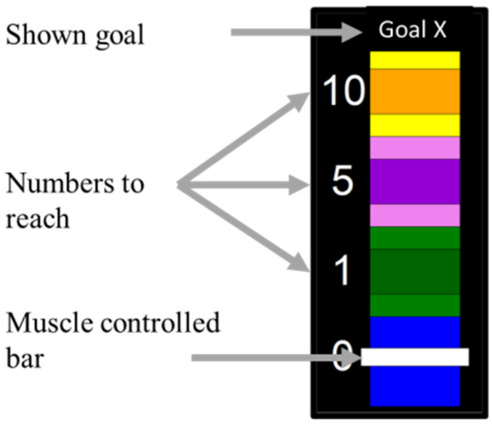

Figure 1: Muscle-controlled serious game. The white bar is controlled by muscle activity and moves when muscle activity changes. The digits 1, 5 and 10 are the goals to reach. These goals are shown above the column. When the bar was steered in the correct goal area, a countdown of three seconds appears. After holding the bar in the correct range for three seconds, the muscle can be relaxed and the next goal to reach is displayed.

Table 1: Goals with the corresponding muscle activity calculated out of the maximal voluntary contraction (MVC).

goals	muscle activity
goal 0	0%-20% of MVC
goal 1	20%-40% of MVC
goal 5	40%-60% of MVC
goal 10	60%-80% of MVC

2.2.2 Experimental Set-up

Seven sets of the game were played for training with a following learning control set each of the three days in a row. In each set (training and learning control set) every number had to be reached three times. The order was randomized. The learning control set consists of a set in which the subjects didn't receive any feedback of the game. It just showed the target and the subjects had to contract the muscle the right way out of their memory. After they assumed they were in the right area for least three seconds without feedback, they had to relax the muscle and the next target was displayed. A detailed description of the experimental design is depicted in Figure 2.

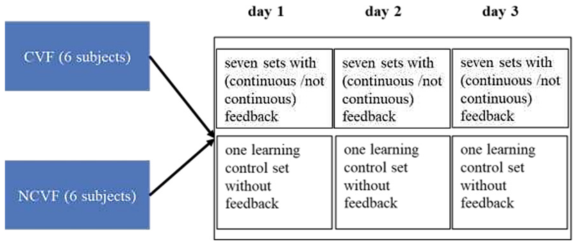

Figure 2: Description of the experimental setup. Subjects of both groups played the game on three days in a row. Every day consists of playing seven sets with one of the feedback methods and one set of a learning control set without feedback.

2.2.3 Data Processing

The analysis of the data is divided into two parts. The analysis of the training set data and the analysis of the learning control set data. The analyzed training set data consists of the data collected from the moment that the goal to reach was displayed till the moment the goal was achieved. Out of these data the average time taken by a subject to achieve each goal of the training sets was determined. The time was calculated over seven training sets for each goal on each day for all subjects.

For the learning control sets, the period from the moment that the goal was displayed until the muscle was relaxed again (reached area "0") was determined. It was calculated for every goal on each day for all subjects of each group. Subjects had to reach each goal for three times. As no feedback was given during the learning control set, subjects did not know whether or when they achieved the goal. To evaluate the success the average longest time period (calculated out of three) that a subject spent continuously in the respective goal areas was determined for each day. The time needed to achieve this longest continuous time period in the correct range was determined. This was carried out for each subject on each day for all goals

As the test subjects did not receive any feedback in this sets, they may not have achieved the targets at all. The total missed goals were calculated for each subject of the groups as well.

For the analysis of the results of the training sets, time needed to reach the goals was investigated. The detection of motor learning in the learning control set is counted as a decrease in missed goals. An increase in time (s) spent in the correct area and a decrease in time (s) to achieve the longest period of time spend in the correct range will be also counted as a learning effect.

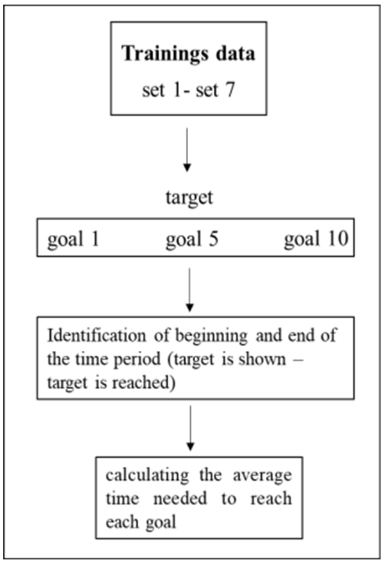

Figure 3: Description of the data processing of the training set data. This process was applied every day's data sets.

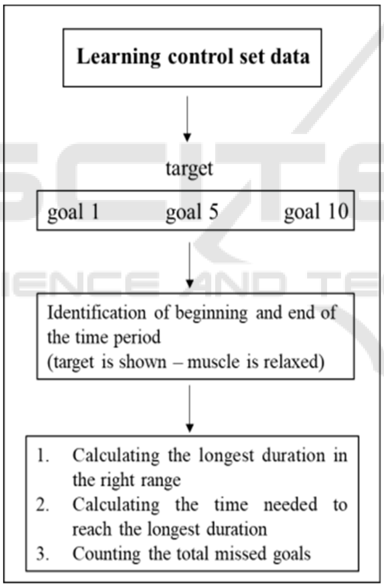

Figure 4: Description of the data processing of the learning control set data. This process was applied on every learning control set data.

2.3 Statistical Analysis

For the statistical analysis a two-sided independent, not paired Wilcoxon-Mann-Whitney test was performed. The data for the analysis consists of two parts. First the average time needed to reach each goal on each day was calculated. The test was performed between the average time of the CVF group and the NCVF group of each day individually. Second, the average time needed to achieve the longest period of time continuously spend in the correct range was also analyzed. The test was performed between the average time of the CVF group and the NCVF group of each day individually. The significance value was set to $p < 0.05$.

3 RESULTS

3.1 Results of the Training Sets

The following section consists of the analysis of the time needed to reach the goals in the training sets. The time is given in seconds.

3.1.1 Analysis of the Time Needed to Reach the Goal

Figure 5 depicts the comparison of the average time (s) the NCVF group needed to succeed in each goal between the training sets of the three days. The average time to reach the single goals decreased for goal 5 and goal 10 within the days. For goal 1 the time was lowest on day 2 and highest on day 1 and day 3. The highest time differences occurred between day 1 and day 2 in goal 10. The lowest differences were found between the time differences of goal 1. Goal 1 was reached fastest on every day. Goal 10 was reached slowest on every day.

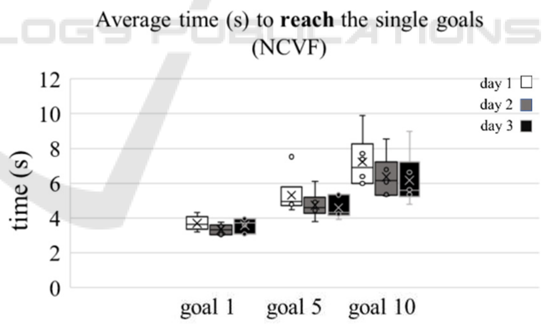

Figure 5: Comparison of the average time (s) the NCVF group needed to succeed in each goal between the training sets of the three days.

Figure 6 depicts the comparison of the average time (s) the CVF group needed to succeed in each goal between the training sets of the three days. It can be seen that the average time to reach the single goals decreases for every goal over the days. The highest time differences occurred between day 1 and day 2 in goal 10. The lowest differences were found between the time differences of goal 1. Goal 1 was reached fastest on every day. Goal 10 was reached slowest on every day.

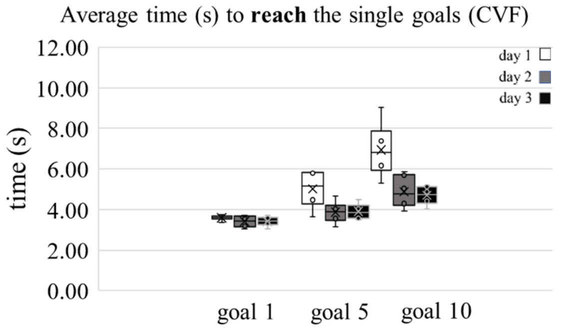

Figure 6: Comparison of the average time (s) the CVF group needed to succeed in each goal between the training sets of the three days.

Figure 7 depicts the comparison of the average time to reach the goals between the CVF group and the NCVF group of the three days. Each Boxplot consist of the average time for reaching the goals in the training sets of each subject in the groups. The average time for reaching the goals decreases for both groups within the days. On day 2 and day 3 the needed time for reaching the goals is less in the CVF group compared to the times of the NCVF group. However, these results are not significant.

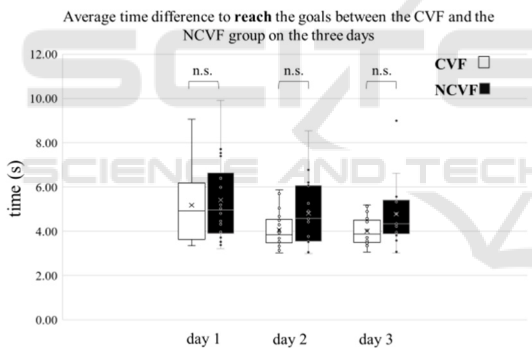

Figure 7: Comparison of the average times needed to reach the goals in the training sets between the CVF and the NCVF groups on three days.

3.2 Results of the Learning Control Set

The following section consists of the analysis of the total number of missed goals and the time needed to reach the goals in the learning control sets. The time is given in seconds.

3.2.1 Analysis of the Total Number of Missed Goals

Subjects had to reach every goal three times in one learning control set. Table 2 depicts the total number of missed goals on every day in the NCVF group. For goal 1 the number of missed goals does decrease from five to zero within the three days. The missed goals for goal 1 consist of three subjects. For goal 5 the missed goals were five for day 1, seven on day 2 and four on day 3 (5 subjects). The missed goals for goal 10 on day 1 was one, on day two it was five and four on day 3 (3 subjects).

The total number of missed goals on every day of the CVF group is depicted in Table 3. For goal 1 the missed goals on day 1 were 0, on day 2 five and on day 3 the number of missed goals was one (3 subjects). For goal 5 the missed goals on day 1 and day 2 were two and on day 3 three. For goal 10 the number of missed goals was one on every day.

Table 2: Total missed goals of the NCVF group in the learning control sets of each day.

	total missed goals NCVF group								
	Goal 1			Goal 5			Goal 10		
day	1	2	3	1	2	3	1	2	3
missed goals	5	3	0	5	7	4	1	5	4

Table 3: Total missed goals of the CVF group in the learning control sets of each day.

	total missed goals CVF group								
	Goal 1			Goal 5			Goal 10		
day	1	2	3	1	2	3	1	2	3
missed goals	0	5	1	2	2	3	1	1	1

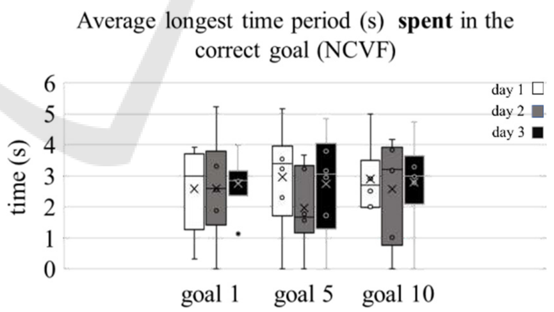

Figure 8: Comparison of the average longest period of time (s) spent in the correct goal between the three days. Depicted is the NCVF group in the learning control set.

3.2.2 Analysis of the Time (S) Needed to Reach the Goal

As in the learning control set no feedback was given on how many seconds were spent in the right range, the longest duration spent in the right range was calculated as well as the time needed to achieve the longest time period spent in the correct goal.

Figure 8 depicts the comparison of the average longest period of time spent continuously in the correct goal between the three days of the NCVF group. For goal 1 and goal 5 the longest period of time spent continuously in the right range was on day 1 and the shortest on day 2. The median is around 3 seconds on day 1 and day 3. For goal 10 the longest period of time spent continuously in the correct range was achieved on day 2 and the shortest on day 1. The median is around 3 seconds on day 2 and day 3. Figure 9 depicts the comparison of the average time(s) needed to reach the correct goal between the three days of the NCVF group. Longest time to reach longest period of time spent continuously in the correct goal was needed on day 1 for every goal. For goal 1 the shortest time was needed on day 2. The shortest time needed to reach the longest period of time spent continuously in the correct range for goal 5 and goal 10 was on day 3. The time decreases for every goal within the days.

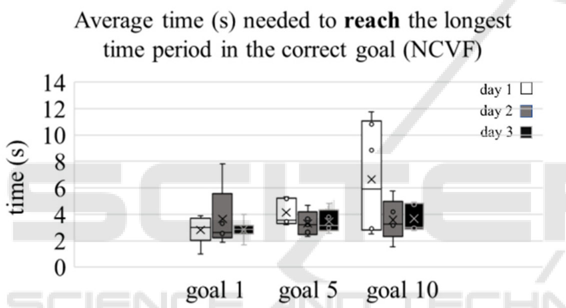

Figure 9: Comparison between the average time (s) needed to reach the longest time period in the correct goal between the three days. Depicted is the NCVF group in the learning control set.

Figure 10 depicts the comparison of the average longest time period (s) spent continuously in the correct goal between the three days of the CVF group. For goal 1 and goal 10 the longest period of time spent continuously in the right range was achieved on day 3 and the shortest on day 2. For goal 5 the longest period of time spent continuously in the correct goal was on day 1 and the shortest on day 2 as well. Apart from goal 1 on the second day, the targets were always held for at least three seconds on average. Figure 11 depicts the average needed time to reach the longest period of time spent continuously in the correct goal for each goal on every day. For goal 1 and goal 10 the shortest time needed to reach the longest period of time spent continuously in the correct goal was achieved on day 2 and the longest time was needed on day 3. For goal 5 the time slightly decreases within the days.

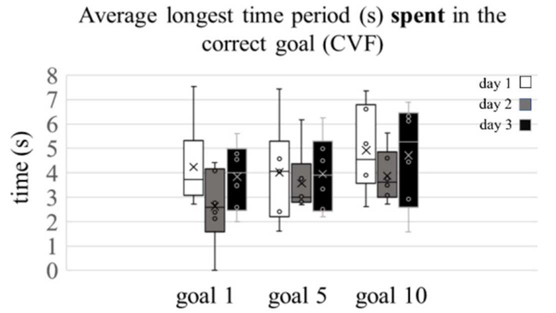

Figure 10: Comparison of the average longest duration (s) spent in the correct goal between the three days. Depicted is the CVF group in the learning control set.

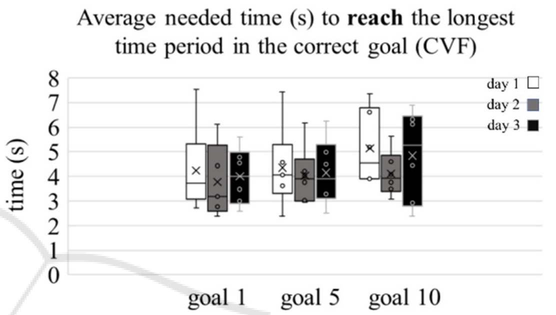

Figure 11: Comparison of the average time (s) needed to reach the longest duration in the correct goal between the three days. Depicted is the CVF group in the learning control set.

Figure 12 depicts the comparison of the average time needed to reach the longest period of time in the correct goal between the CVF group and the NCVF group of the three days. Each Boxplot combines the data of all goals of each day.

The CVF group needed more time compared to the NCVF group on day 1 and day 3. On day 2 both groups are almost the same. However, the results are not significant.

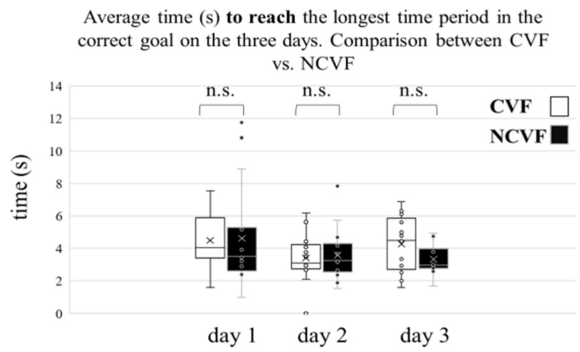

Figure 12: Comparison of the average time needed to reach the longest period of time in the correct goal on each day between the CVF group and the NCVF group in the learning control set.

4 DISCUSSION

Both groups improved their average time to succeed in reaching the goals in the training sets within the days. However, the success in the training sets for the CVF group was faster on average although the differences are not significant. It seems that continuous visual feedback helped reaching the goals faster although differences were not significant. This criterion corresponds more to a training effect than a learning effect.

Based on the results from the training sets, the decrease in the time to reach the correct target could lead to the assumption that there was an improvement in the CVF compared to the NCVF.

However, if we now look at the results from the learning control sets, this does not appear to be transferable. Since a countdown of three seconds was displayed in the training sets when the bar was in the correct area, the sense of timing could be practiced. Except of day 2, the CVF group spent on average more than 3 seconds in the correct area. The NCVF group spent on average very close to three seconds in the correct range on all three days. This could lead to the assumption that the CVF group was more uncertain or more cautious in the execution of the task which could be a sign of stronger dependency on feedback. Moreover, the time required to reach the longest period of continuous time spent at the correct target decreased in the NCVF group. In the CVF group, this time increased on the third day compared to day 1. On the other hand, the number of missed targets was lower in the CVF group than in the NCVF group. While some criteria that were defined as motor learning for the learning control sets were fulfilled by both of the groups the observed results appear to be controversial. One could assume that the CVF group was more insecure in the learning control sets, which is why they needed more time to reach the targets and stayed longer in the targets to make sure they had reached them long enough. Nevertheless, fewer goals were missed in the CVF group. The observed improvement in the time to achieve the goals in the learning control sets for the NCVF group as well as the more exact duration in the correct goal compared to the CVF group is consistent with results from previous studies, which showed that a greater learning effect occurs with non-continuous feedback compared to continuous feedback (Marco- Ahulló, et al. 2024; Sullivan, Kantak und Burtner 2008; Sülzenbrück und Heuer, 2011).

Nevertheless, the results of our study must be interpreted with caution, as our results are not significant and some are controverse. To be able to make a clear statement regarding the guidance hypothesis, it would be useful to carry out more than three training days and more test subjects to see whether more of the defined criteria for motor learning are fulfilled and whether the found differences prove to become significant with a larger number of subjects.

5 CONCLUSION

Both groups fulfill predefined criteria for motor learning, even though the results are not statistically significant. Since some of the results are controversial, extending the investigation to more than three test days and including additional subjects would be beneficial in order to provide a clearer statement regarding the guidance hypothesis.

ETHICS STATEMENT

The studies involving human participants were approved by the local Ethical Committee of the University of Duisburg-Essen, Germany. The participants provided their written informed consent to participate in this study.

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