Determining the location of effects and their validity for obstacle avoidance tasks.

Cédric van Beijsterveldt (3365042)

Introduction

Reaching and grabbing an object is a common practice in every day life. It is a task that humans perform numerous times on a daily basis, and are mostly quite adapt at. Even though items are often obstructed by different obstacles, people are usually able to grasp them without touching anything that stands between the target object and the person reaching for it. Reach-to-grasp movements, that, as the name implies, involve the movement of a hand to an object with the purpose of grabbing it, have therefore been subjected to many studies (Castiello, Bennett & Stelmach (1993); Tipper, Howard & Jackson (1997); Tresilian (1998); Saling, Alberts, Stelmach & Bloedel (1998); Hu, Eagleson & Goodale (1999); Kritikos, Bennett, Dunai & Castiello (2000); Mon-Williams, Tresilian, Coppard & Carson (2001) ; Antonia, Hamilton & Wolpert (2002); Alberts, Saling & Stelmach (2002); Zahariev & Mackenzie (2007); Eastough & Edwards (2007); Chapman & Goodale (2008); Sangole & Levin (2008); Butler, Ladd, LaMont & Rose (2010); Hesse & Deubel (2010); Bae & Armstrong (2011)). Researchers have been concerned with the influence of non-target objects placed at a different location (Tipper et al. (1997); Saling et al. (1998); Kritikos et al. (2000)) and the influence of object size (Castiello et al. (1993)), as well as the way in which the hand palm changes shape during an obstacle avoidance task (Sangole et al. (2008)).

When reaching past obstacles, it is often suggested that the person performing the task requires some sort of buffer between his hand and the obstacle (Tresilian (1998). The size of this buffer depends on different aspects, such as the speed of the movement and other psychological factors that are linked to the performers' desire not to hit the obstacle. Effects caused by obstacles are, for example, lateral deviation of the trajectory path and deceleration of velocity. Thus far, research has also indicated that non-targets do not necessarily have to be physical obstructions to cause interference with the grasping task (Tipper et al. (1997), Tresilian (1998); Kritikos et al. (2000), Mon-Williams et al. (2001)), as effects can also be caused by the mere presence of a non-target. In this case, it is implied that the non-target captures the attention of the person reaching, invoking competing responses. The inhibitory mechanisms that resolve this competition are suggested to reveal this struggle in the reaching path, like bending the hand trajectory towards a distractor (Tipper et al. (1997)). This characteristic, though, is in contrast with some aspects of motor control (Hamilton et al. (2002)), as this study suggests that trajectories made during obstacle avoidance tasks are (close to) optimal, whereas the distractor model allows for reaches to be suboptimal when compared to a control. The obstacle model does account for this, predicting hand trajectories to come as close to an obstacle as the buffer allows it. Studies for both models concentrate mostly on aperture, velocity and movement time. There is still no consensus on whether the effect of not-obstructing non-targets has to be interpreted using the non-targets' obstructing or distracting effects, causing a division between those researching obstacle avoidance. Some research finds results to be in line with the obstacle model (Tresilian (1998)), while other experiments are seen as proof for the distractor model (Tipper et al. (1997); Kritikos et al. (2000)).

To measure the data in these experiments, the positions of trackers attached to the hand and / or fingers are taken. A typical graph that can be made from this data is displayed in figure 1.

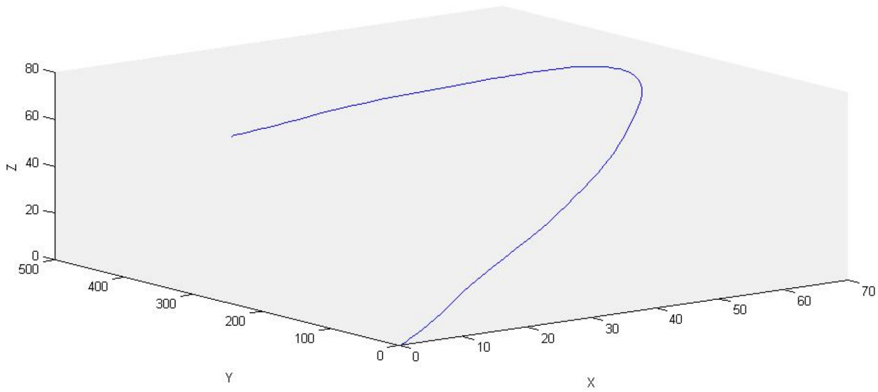

Figure 1 Example of a single 3D trajectory plot of a reach-to-grasp task. The data was collected using electromagnetic markers connected to a MiniBird system (Ascension Technology Corporation, Burlington, USA). The starting point of the task was at (0,0,0), the target was located at (0,420,0).

Nonetheless, once researchers want to compare different experimental conditions they no longer rely solely on the trajectory of the movement, but also use different sets of kinematic parameters. Kinematic parameters that have been used are, for example, aperture (the distance between the index finger and thumb) (Castiello et al. (1993), Tresilian (1998), Saling et al. (1998), Hu et al. (1999), Kritikos et al. (2000), Mon-Williams et al. (2001), Alberts et al. (2002), Zahariev et al. (2007), Eastough et al. (2007)), angle (the angle between the index finger and thumb) (Tipper et al. (1997), Eastough et al. (2007)) and velocity (the speed of the movement at a given time) (Castiello et al. (1993), Saling et al. (1998), Hu et al. (1999), Kritikos et al. (2000), Mon-Williams et al. (2001), Alberts et al. (2002), Zahariev et al. (2007); Eastough et al. (2007), Chapman et al. (2008); Butler et al. (2010)) and movement deviation, with the direction of the deviation depending on the researched effect (Saling et al. (1998) , Kritikos et al. (2000)). Variations on these parameters are used as well, e.g. the maximum value, or peak, of a parameter during a single task and the relative timing at which that peak occurs.

Thus far, no widely acknowledged standards have been developed to determine the requirements that obstacle avoidance studies and experiments have to meet before they can be accepted as being valid. Because of this lack of standards, researchers have to make their own, often subjective, choices in this regard, leading to fragmentation of the scientific field and incomparable studies. As an example of this, there is no standard on how to instruct participants during an experiment. Researchers are not required to use a particular term to define movement speed during a task, and can choose to instruct participants to reach either ‘normal’ or ‘fast’ while often failing to mention this in their studies. This difference in instruction could, however, lead to different results (van Dijk (2012)).

As another example, it is mostly assumed that, during obstacle avoidance tasks, variance is homogeneous between conditions. The ‘analysis of variance’ (ANOVA) test, which is often used to determine the presence of an effect, does depend on this assumption though. This could lead to results that are based on this test to become questionable. It is therefore the scope of this study to determine whether or not it is possible to define trajectory intervals in which effects on certain parameters are most likely to be found, and if these found effects can be considered valid by testing for the homogeneity of variance for these intervals. This will be done by analyzing trajectories for lateral deviation, aperture and velocity, as these parameters are commonly used when studying the influence of non-targets during an obstacle avoidance task.

The experiment was designed with the purpose of collecting trajectory data for different movement paths instead of directly trying to find evidence for the existence of a certain effect. The different conditions therefore consisted of simple prehension tasks and required participants to reach for and grab a target object with or without an obstacle or distractor being placed between the participant and the target.

Using the results of previous studies, it was expected that movement trajectories would become longer, i.e. a larger deviation in the x-trajectory, if non-targets were placed closer to the movement path of the control condition, as to avoid collision with the non-target (Tipper et al. (1997). Also, previous research indicated that the different positionings of a non-target would cause differences in both velocity (Mon-Williams et al. (2001)) and aperture (Tresilian (1998); Mon-Williams et al. (2001)). Therefore, it was hypothesized that, at a given point of measurement, a non-target would cause a larger lateral deviation and a lower aperture and velocity if it was placed closer to the movement path.

Method

The participants consisted of ten paid right-handed students with normal, or corrected to normal, vision and no serious physical or psychological deficits.

Materials

The participants were seated before a flat table with a workspace of 40 cm by 40 cm, in which two buttons were embedded. These buttons were located on the middle line along the length of the table with a distance of 40 cm between them, as can be seen in Figure 2. One of these buttons was used as a starting point for the prehension movement, the other was used to place the to-be-grasped target on. For both the target and the obstacle, wood-coloured, identically sized, wooden cylinders were used (5.1 cm in diameter, 15.1 cm in height). For the 'no-grasp' condition, a red-coloured cylinder was used.

The movements were measured by two electromagnetic markers placed on the participants' right thumb and index finger. The other ends of these markers were attached to the MiniBird system (Ascension Technology Corporation, Burlington, USA), which translated the input from the markers into x, y, and z position data.

To prevent participants from examining the task before the start of every trial, PLATO LCD goggles (Translucent Technologies, Toronto, Canada), were used. These lenses would become clear during task execution and become opaque again once the participants had completed the task. The task was completed after participants had lifted the target and returned their hand to press the starting button.

Procedure

The participants were placed on a chair before the table, in such a way that their right index finger would touch the starting button. Their right arms were under an angle of 45 degrees relative to the side of the table they were placed behind. They were instructed to keep an upright posture.

Participants were given the task to reach towards and grab the target cylinder once they heard an auditory signal, which could be heard between 800-1200ms after the trial had started. Trial start was initiated by the experimenter upon setting up the spatial configuration of target and obstacles required for a given trial. At the same time as the auditory signal, the lenses of the PLATO goggles would become clear. After initiation and completion of the reach-to-grasp movement the participants were then required to place the cylinder back and return their hand to press the starting button, resulting in the lenses becoming opaque again. After this the participants had to assume their ‘fixed’ starting posture.

Design

The experiment consisted of a total of a total of 110 trials, of which the first 10 were test trials. The remaining 100 were divided in two blocks, which will be referred to as block 1 and block 2, consisting of 50 trials each. The number of trials in block 1 and 2 were evenly divided across the five conditions used in the experiment, resulting in 10 trials per condition for both. The practice block contained five times the control condition, as well as five times the ‘no-grasp’ condition. The order of the trials was randomized per block. Participants were given the option to have a small break between block 1 and 2.

There were three different experimental conditions, as well as a control condition. The layout of these conditions can be seen in figures 2 to 5 below.

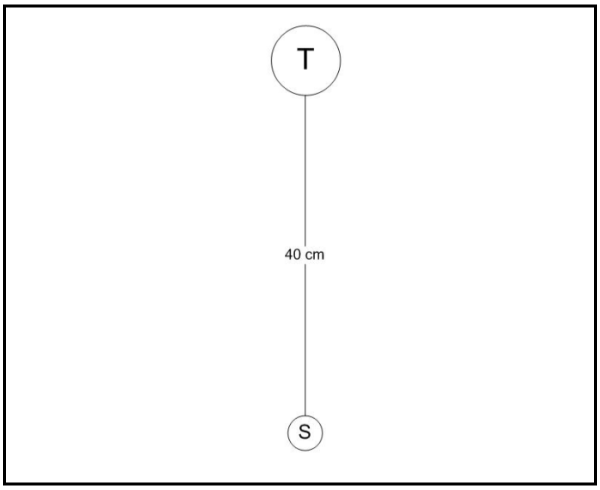

Figure 2 Table layout for the control condition, in which no obstacle / distractor was present. The starting point and target are being represented with ‘S’ en ‘T’ respectively. Distance between the starting button and the target was 40 cm.

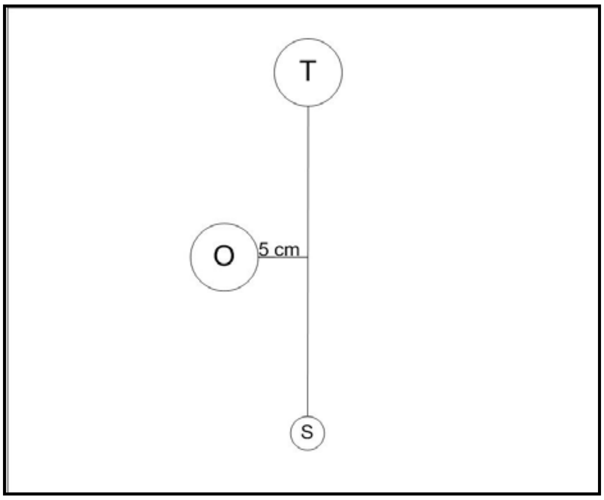

Figure 3 Table layout for the first experimental condition. The obstacle, represented with ‘O’, was placed 5 cm left of the imaginary middle line between starting point and target.

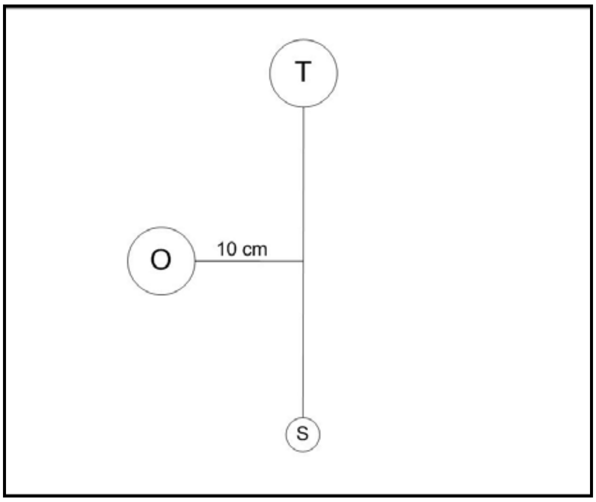

Figure 4 Table layout for the second experimental condition. The distractor, represented with ‘O’, was placed 10 cm left of the imaginary middle line between starting point and target.

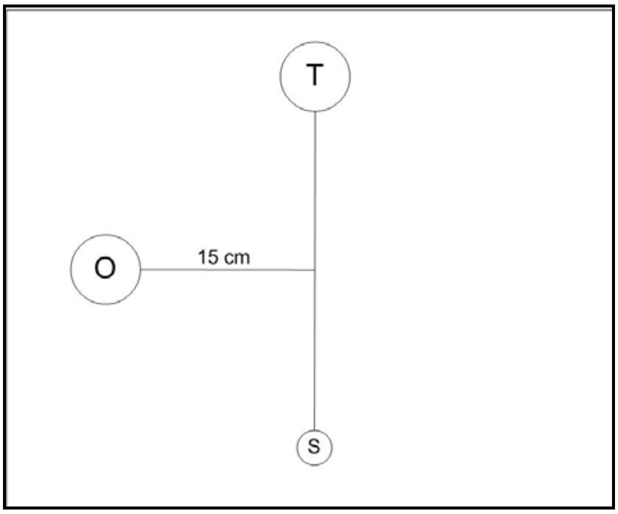

Figure 5 Table layout for the third experimental condition. The distractor, represented with ‘O’, was placed 15 cm left of the imaginary middle line between starting point and target.

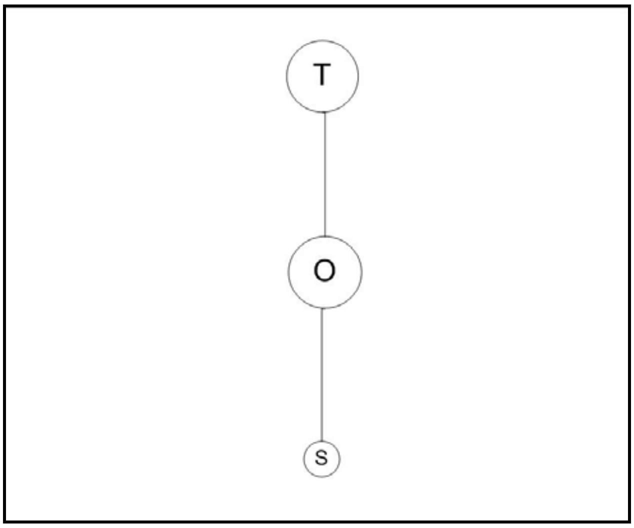

Figure 6 Table layout for the 'non' grasp condition. A red cylinder, represented with 'O', was placed in the middle between starting point and target to instruct the participants not to reach.

Data Processing & Analysis

Data was processed using the Matlab R2010a software (Version 7.10.0.499, The MathWorks, Natick, USA). The used filter was an order 6 lowpass Butterworth filter with a cut-off frequency of 0,4. Movement onset was defined as the point at which velocity of the thumb had exceeded 50 mm/ms for 5 consecutive samples. A movement was said to have terminated once the marker on the thumb had a y-value indicating it was closer than 5 mm from the target object. Furthermore, data for all trials was normalized over time to 100 measurements using a cubic spline interpolation. The two dependent measures, namely aperture and velocity, were then calculated from this data, using the Euclidean distance and vector sum of the normalized x-, y- and z-coordinates respectively.

The resulting data for the three to be researched variables was analyzed using a repeated measurement ANOVA to determine significant effects between the conditions, and a Pitman-Morgan Test to validate the homogeneity of variance. Results from both tests were analyzed using a significance of $\alpha < 0{,}05$.

Results

The standard deviation and standard error were calculated for the mean x-coordinates, averaged per participant over 20 trials per condition, as well as for the mean aperture and velocity, which were averaged in the same way. With the exception of aperture, results are based solely on the movement of the thumb. Most researchers seem to favour the wrist as a means to determine lateral deviation and velocity (Castiello et al. (1993); Saling et al. (1998); Hu et al. (1999); Kritikos et al. (2000); Stelmach et al. (2002); Eastough et al. (2007); MacKenzie et al. (2007); Deubel et al. (2010)). As in this experiment no marker was placed on the wrist, the thumb was chosen to measure lateral deviation and velocity. The mean trajectories per condition over all participants can be seen in figures 2, 3 and 4 for lateral deviation, aperture and velocity respectively. Since the 'no-grasp' condition was only used to prevent participants from developing an automated reach and did not require any prehension from the participants, the measurements obtained from that condition were not used to calculate results.

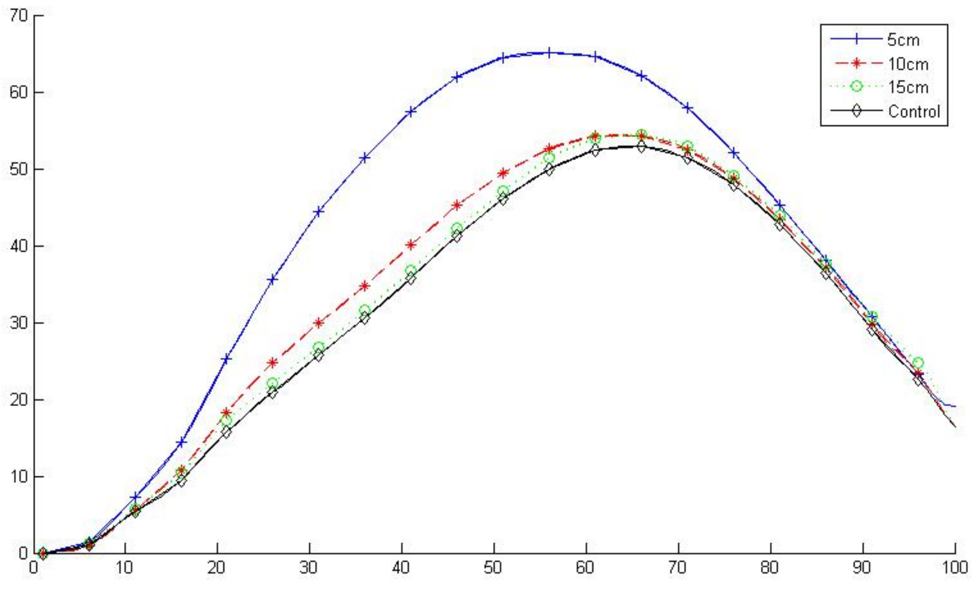

Figure 7 Plot showing the mean lateral deviation per condition over all participants, with the x-axle indicating time passed and the y-axle the deviation in mm.

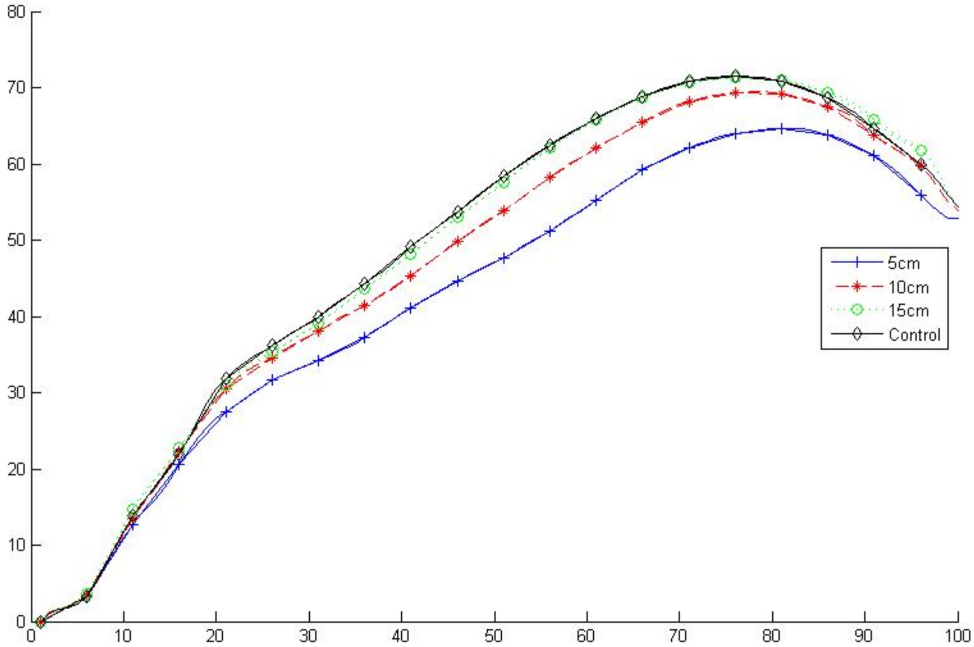

Figure 8 Plot showing the mean aperture per condition over all participants, with the x-axle indicating time and the y-axle the aperture in mm.

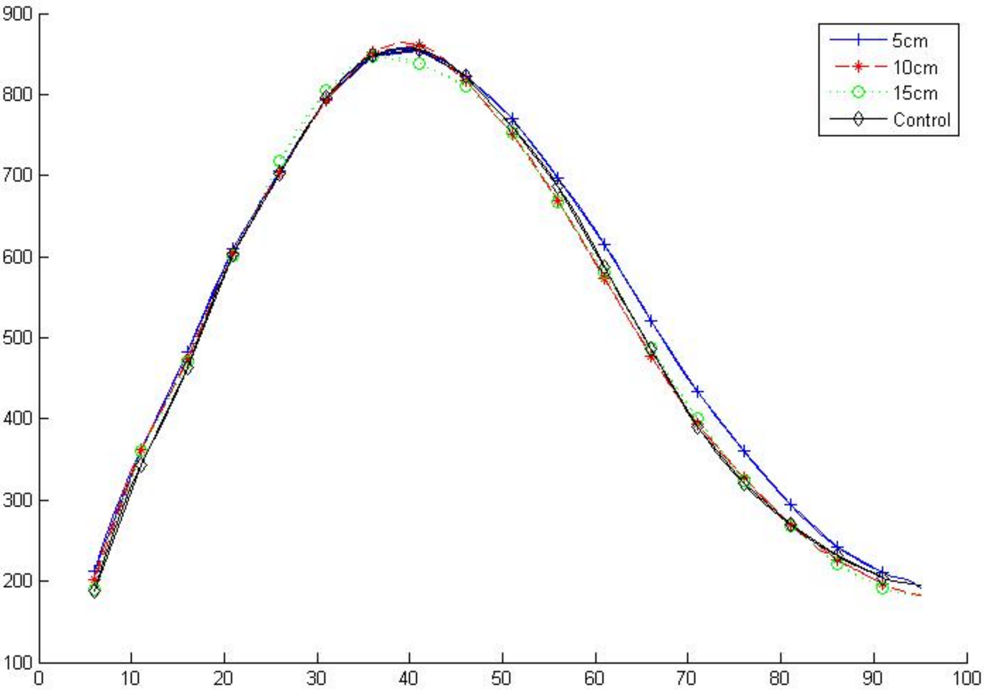

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Figure 9 Plot showing the mean velocity per condition over all participants, with the x-axle indicating time and the y-axle the velocity in mm/ms.

Analyses were performed using a repeated measurement ANOVA for a full comparison between all conditions. In addition, a Pitman-Morgan Test (Pitman (1939); Morgan (1939)) based on a t-test (Gardner (2001)) was used to analyze the homogeneity of variances between comparisons[1]. Both the repeated measurements ANOVA and the Pitman-Morgan test were done for lateral deviation of the thumb, aperture and velocity.

Repeated measurement ANOVA results

Condition	X-coordinates	Aperture	Velocity
5 cm against 10 cm	26-54	No effect	No effect
5 cm against 15 cm	23-56	No effect	No effect
5 cm against control	21-60	No effect	No effect
10 cm against 15 cm	No effect	No effect	No effect
10 cm against control	No effect	No effect	No effect
15 cm against control	No effect	No effect	No effect

Table 1 Results of the repeated measurement ANOVA to compare X-deviation, aperture and velocity between all conditions with a significance of $\alpha < 0{,}05$. The displayed numbers are the indices on a 0-100 normalized time scale, and indicate the interval(s) in which an effect was found.

As expected, significant effects were found for lateral deviation between some conditions where the non-target was close to the transport path, as compared to those where this was not the case. The only condition in which, when compared to another one, the non-target was close enough to significantly alter the path of the movement was the one in which the non-target was placed 5 cm from the middle. Comparisons between the other three conditions did not yield any significant effects. As can be seen in Table 1, the interval of the effect also increased slightly when the non-target in the compared condition was placed further away from the transport path. Contrary to the hypothesis, however, this did not

[1] http://how2stats.blogspot.nl/2011/06/testing-difference-between-correlated.html

seem to be the case for both aperture and velocity. Even though, as shown in Figure 3, small differences in aperture were found between some of the conditions, none of them proved to be significant. Looking at the plotted values of velocity on the other hand (Figure 4), it is not surprising no effects were found, as the plotted graphs seem to differ very little from each other.

Pitman-Morgan Test results

As said before, the Pitman-Morgan Test was used to determine the homogeneity between the variances of all conditions. For this test, the mean variances per condition over all participants were calculated and compared.

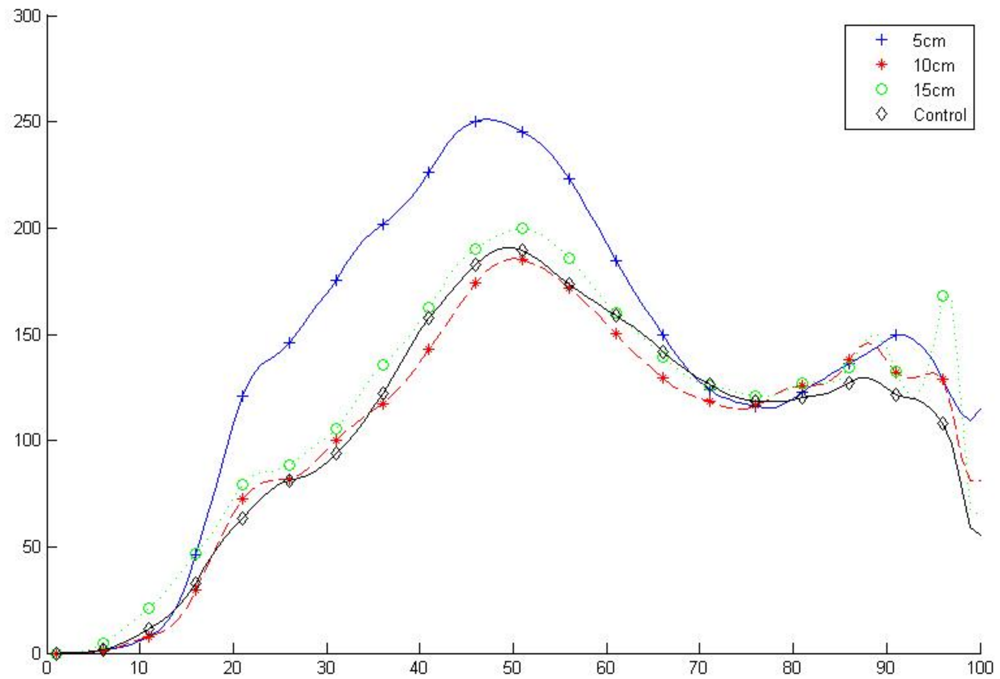

Figure 10 Plot of the mean variances of the lateral deviation per condition over all participants, with the x-axle indicating time and the y-axle the variance in mm.

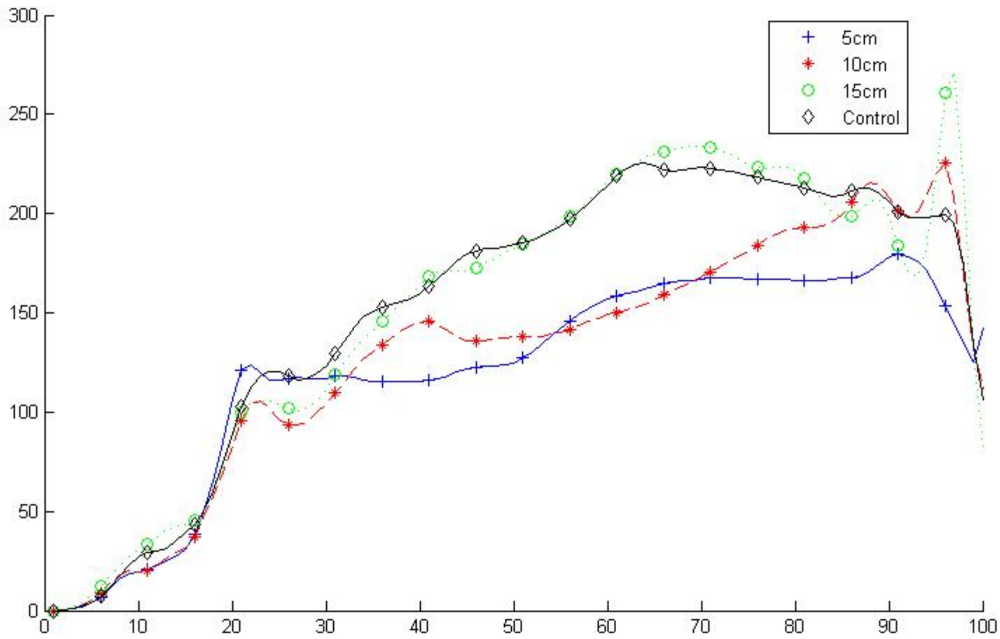

Figure 11 Plot of the mean variances of the aperture per condition over all participants, with the x-axle indicating time and the y-axle the variance in mm.

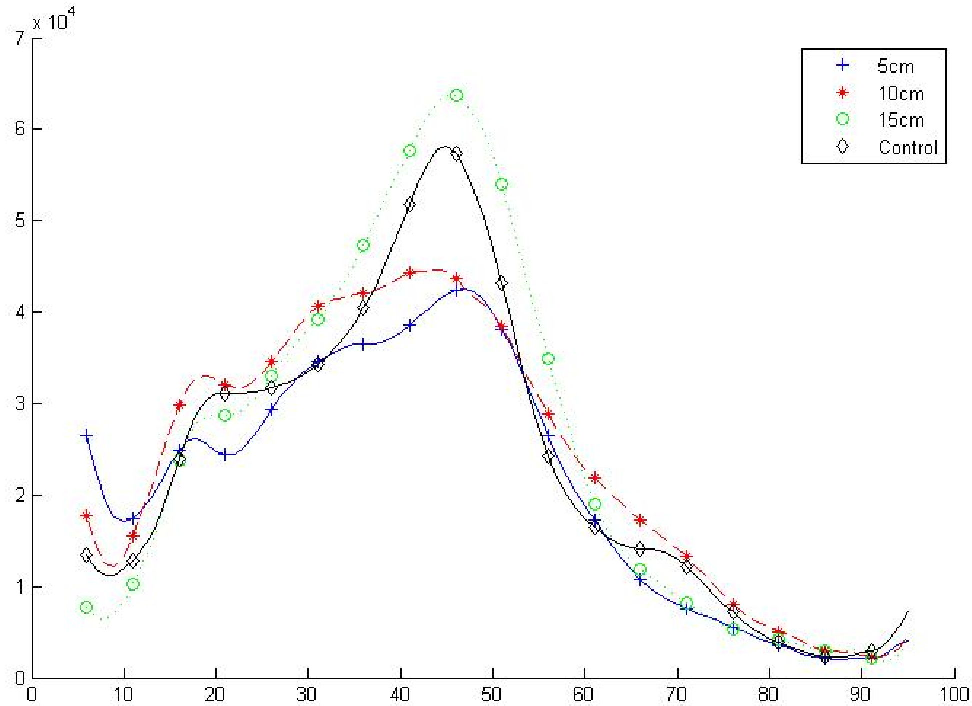

Figure 12 Plot of the mean variances of velocity per condition over all participants, with the x-axle indicating time and the y-axle the variance in mm.

Condition	X-coordinates	Aperture	Velocity
5 cm against 10 cm	2-5	No effect	6-9, 64-76, 82-84
5 cm against 15 cm	3-13	3-6, 97	6-11
5 cm against control	3-4, 20-23, 27-33, 99-100	No effect	6-8, 69-71, 95
10 cm against 15 cm	2-17, 96-97	No effect	6-9, 72-73
10 cm against control	2-7, 10-14, 99-100	No effect	93-94
15 cm against control	2-16, 96-98	3-7, 97	6-10, 53-59, 68-76, 92-95

Table 2 Results of the Pitman-Morgan Test to determine the homogeneity of the variances of the X-deviation, aperture and velocity between all conditions with a significance of $\alpha < 0{,}05$. The displayed numbers are the indices on a 0-100 normalized time scale, and indicate the interval(s) in which an effect was found.

As Table 2 indicates, variances were not homogeneous for all compared measurements, or at least not over the entire trajectory. Figures 6, 7 and 8 show plotted comparisons of the variances for the X-deviation, aperture and velocity respectively. In most cases, significant differences occurred mostly at the beginning or towards the end of a prehension.

Discussion

Unfortunately, the repeated measurement ANOVA only yielded significant results when comparing lateral deviation. However, the intervals derived from these results do all centre around the same time during the prehension, namely at roughly 40% of the movement. This indicates that the different conditions caused an effect around the same intervals and that this effect is not dependant on the lateral distance of the non-target. The borders of these intervals increased similarly at both ends as comparisons were made with more distant non-targets. In addition, the Pitman-Morgan Test did not indicate a significant difference in variance for two of these three intervals, namely when comparing the first condition, in which an obstacle was placed 5 cm left from the line between starting point and target, to those in which the distractors were positioned 10 and 15 cm to the left. When comparing this first condition to the control condition, however, a significant difference in variance was found, contradicting the assumption of the ANOVA that variances are roughly the same. Still, even in this comparison, this was not the case for the entire interval, validating the fact that the obstacle did cause interference when compared to the control condition. Therefore, it can be suggested that, at least for lateral deviation, intervals for significant effects can be determined, though their variance should be tested for homogeneity when using a test based on that assumption. Since the experiment performed for this study did not yield any significant effects for aperture and velocity, no suggestions can be made on whether or not such intervals can also be found for these parameters. It also implies, however, that homogeneity of variance can not always be assumed when comparing reach-to-grasp tasks. This could have an impact on the validity of previous studies, in which results were derived from tests working under the assumption that did was the case, such as the ANOVA test. Still, as was the case in this experiment, even if variance between conditions is found to be heterogeneous, this does not necessarily have to be the case for the entire interval of the effect. Therefore, conclusions concerning the existence of certain effects could still be considered well-grounded if significant differences in variance were only found for a small number of measurements. The allowed number of heterogeneous variances would still have to be determined though, which goes beyond the scope of this study.

Interestingly, significant heterogeneous variances were also derived from comparisons for which no significant effect was found with the repeated measurement ANOVA. This could imply that, although the exact measures may not differ significantly between these conditions, there still was an interference caused by the non-target which resulted in the participants' prehension being more varying for some conditions. In addition, it implies that a homogeneous variance in experimental settings where effects for aperture and velocity are found can also not be simply assumed.

As expected, lateral deviation proved to show significant effects between some conditions. However, contrary to the hypothesis, no effects were found for both aperture and velocity. In addition, the hypothesis assuming the homogeneous variance between conditions also proved to be invalid, although the impact of this on the results will yet have to be determined. Still, this may have implications for the conclusions of any research on obstacle avoidance done under this assumption, as conditions may not been legitimately compared. Therefore, tests such as the Pitman-Morgan Test ought to be included more often when conducting research in this field.

It should be noted though that the results from this study were based on a particular experimental setting, and may therefore not be directly applicable to other experimental designs. The size and location of effect intervals can differ, for example, as non-targets are placed at different locations. Although it is expected that these intervals will be found around obstacles and distractors in a similar fashion as in this experiment, this cannot be concluded from merely this study.
Variances, as well, may differ based on location, size or other non-target properties. Therefore, if in one comparison a non-target has been proven to contain no significantly different variances, this should not be assumed if the non-targets were to differ in, for example, height. As such, since very little research on homogeneity of variance in obstacle avoidance tasks has been done so far, this assumption cannot be made arbitrarily.

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Abstract

Reach-to-grasp movements, in combination with obstacle avoidance, have been the subject of many studies. However, as no widely acknowledged standards have yet been developed concerning the conduction of experiments and analysis of results, researchers in this field often have to make their own choices when studying these movements. As an example of this, data is often analyzed with the assumption of homogeneous variances between conditions. Therefore, it was the scope of this study to determine the validity of that assumption, by determining the intervals during which an effect was found while performing an obstacle avoidance task and testing these intervals for heterogeneous variances. This was done for the kinematic parameters lateral deviation, aperture and velocity. In the case of lateral deviation, heterogeneous variances were found within the interval of a significant effect. As for aperture and velocity, no effects between conditions were found. Namely for velocity, though, significant differences were still found, implying both an interference caused by some conditions, as well as the need to test for homogeneous variance if effects in other experimental setting are to be found. In conclusion, the assumption of a homogeneous variance between condition can not be made arbitrarily.