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BACHELOR THESIS

Localisation of short duration stimuli observed during head and eye saccades

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Abstract

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Even during movement of the head and the eyes, we can observe and localize visual stimuli presented to us. While being passively moved however, we seem to be unable to correctly determine whether a short duration visual stimulus is moving with us, or is stationary in space. The projection of the briefly presented stimulus on the retina of the eye does not provide enough information for the brain to differentiate between the two. It therefor concludes that the stimulus is moving in the same direction and with the same speed as our gaze. During active movement, the brain has more information about the movement of the head and the eyes. Does this extra information enable us to correctly localize short duration (visual) stimuli during active movement? In this study, we found that the brain can correctly localize the short duration stimuli. We were unable to conclude what extra information the brain uses to accomplish this. A second finding is that we are able to appropriately observe and localize auditory and bimodal stimuli during active movement, even those presented for a very brief amount of time.

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Chapter 1

Introduction

1.1 Observing the world around us

We observe the world mostly with our eyes and ears. the parts of the brain that analyze the signals coming from our eyes and ears are highly advanced and complex. Because of the importance of these systems, they have been extensively studied in the past. Despite these studies, there are still unanswered questions, two of which we will address in this thesis. We will be focusing on observing targets (stimuli) while our eyes and head are already moving towards an earlier observed stimulus.

1.2 Localization during saccadic movement

In 2005, Vliegen et al proposed that ’the visuomotor system adequately processes dynamic changes in visual input that result from self-initiated gaze shifts, to construct a stable representation of visual targets in an absolute, supraretinal (e.g., world) reference frame.’ [Vliegen, Van Grootel, and Van Opstal, 2005] They concluded this from double saccade experiments in which the second target was presented during the gaze movement of the subject to a first target. Because the subjects were able to precisely localize the second target, they concluded that a preprogrammed gaze-motor command could not be enough to incorporate the fast, dynamic changes of the retinal input due to the second presented target. This meant that people can obtain and process new visual information during saccadic eye and head movement. How we were able to do this, was still unknown.

1.3 Coordinate transformations

In this thesis, movement of the head and/or eyes to localize a stimulus will be referred to as a saccade. When the brain plans a saccade, it plans movement of the eyes, head and body at the same time to change the position of the gaze to the desired location. In this thesis we assume that the body will remain stationary, so we do not have to take the position of the body into consideration. The definition of the gaze (G) will than be the sum of the orientation of the eyes in the head (E) and the head in space (H). This will be consistent throughout this thesis.

$$G = E + H \tag{1.1}$$

Because the visual map in the superior colliculus is in gaze coordinates, the brain has to make two coordinate transformations when planning the movement of the eyes and the head. To get to a target location, an eye shift (E_S) and a head shift (H_S) have to be extracted from the required gaze shift (G_S) (equation 1.2). The required gaze shift can be calculated by subtracting the current gaze location from the target location (T) (equation 1.3, figure 1.1).

$$G_S = T - G \tag{1.2}$$

$$G_S = E_S + H_S \tag{1.3}$$

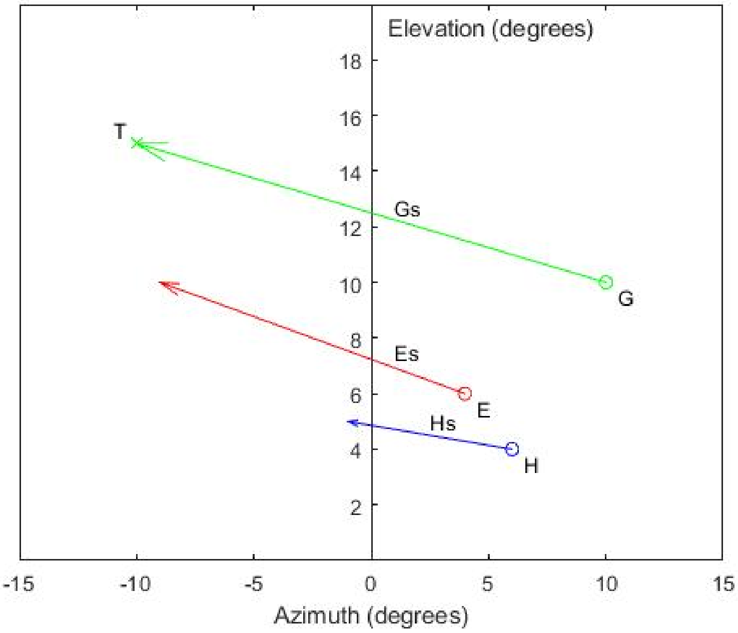

FIGURE 1.1: The sum of the orientation of the eyes in our head (E) and our head in space H is called the gaze (G). A gaze shift (G_S) is therefor the sum of the eyes rotating in the head (E_S) and the head rotating in space (H_S).

Prior research by Goossens and Van Opstal has shown that humans are capable of making the required gaze shifts to correctly localize both visual and auditory targets, even when the head and eyes are initially unaligned [Goossens and Van Opstal, 1997]. When a stimulus is presented while the eyes and head are moving in space, the required gaze shift changes between the time the stimulus is presented and when the gaze shift towards the stimulus is initiated. This difference has to be taken into account for the brain to plan the correct gaze shift. The correct gaze shift is hereby defined as the gaze shift that will result in the gaze landing on the target location.

If we name the position of the gaze when the stimulus is presented T_0 and the position of the gaze when the gaze shift towards the target location is initiated T_1, we can define the correction the brain has to make to the required gaze shift as $T_1 - T_0$. We name this the gaze correction ($G_C = T_1 - T_0$). The correct gaze shift can then be calculated (equation 1.4, figure 1.2).

$$G_S = T_2 - G - G_C \tag{1.4}$$

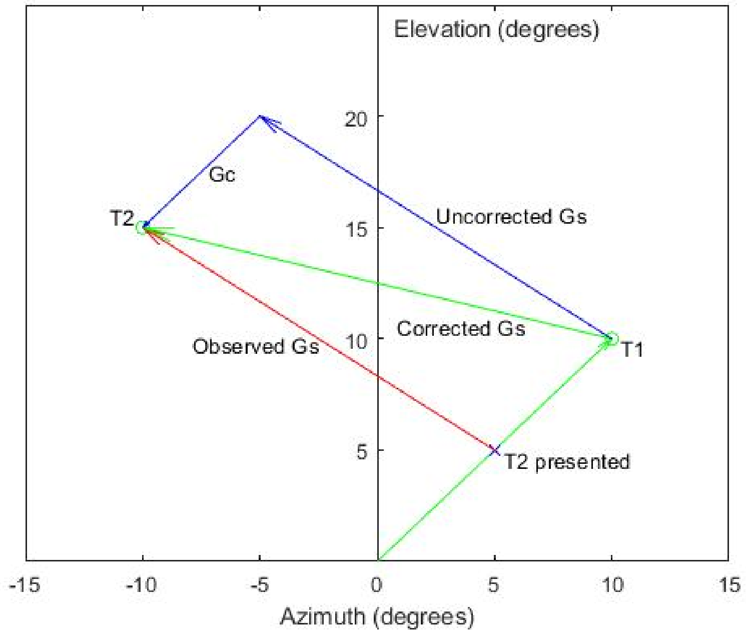

FIGURE 1.2: If a second target ($T2$) is presented during a gaze shift towards an earlier target ($T1$), the brain will make an observation (Observed G_S) that is different from the required movement to localize the target (Corrected G_S). If the brain doesn't incorporate the correction (The gaze correction or G_C), it will make an incorrect gaze shift (Uncorrected G_S) that will not land on the second target.

1.4 Short duration visual stimuli

In 2011, Van Barneveld et al showed that a passively moved subject cannot correctly localize a stimulus stationary in space presented for a very brief amount of time [Van Barneveld, Kiemeneij, and Van Opstal, 2011]. In their experiments, head- and body-restrained humans were rotated sinusoidally. They made eye saccades to visual targets both attached to the chair and stationary in space. If a visual stimulus was presented very briefly, the subjects could not differentiate between the two types of stimuli. Both types of stimuli were treated as stimuli attached to the chair (ie attached to the head). This indicates that the subjects did not incorporate the required gaze correction (G_C) to the gaze shift. For the stimuli attached to the chair, G_C was equal to zero. Therefore, these targets where located correctly. The stimuli stationary in space did need a G_C to be correctly localized. This inability gave valuable information about the way people obtain visual information during movement of the head and eyes.

1.5 Projections on the retina

A possible explanation for this inability could be in the nature of how visual stimuli are detected. Light falls on the retina, where it is transformed to an electrical signal that travels to the brain through the optic nerve [Purves and Augustine, 1997]. If the observer and the target are stationary in respect to one another, the light from the target will create a dot on the retina. However, when the target is moving with respect to the observer, the dot will be moving across the retina, creating a line. It does not matter whether the observer or the target is moving, only that there is a relative movement. The shorter the stimulus and the lower the relative velocity, the shorter the line will be (see Appendix A). If the line is too short, it could be interpreted as a dot by the brain, exactly what you would expect from a stimulus stationary in respect to the gaze. This in turn will lead to an incorrect localization of the stimulus by an amount that is exactly Gc.

1.6 Active and passive movement

An important difference between the Vliegen et al and the Van Barneveld et al experiments, is the use of active versus passive movement. Where in the Vliegen et al experiments the subjects initiated their own movement (a saccade to the location of a first stimulus), the Van Barneveld et al experiments used passive movement. During this passive movement, the subject was being rotated in a chair in a dark room. Because the eyes could not focus on anything in the room due to the darkness, the gaze was moving with the same speed as the chair. Because the speed of the chair could be controlled by the experimenters, they knew the speed of the rotating gaze at the moment the target was presented. In active movement, this is a lot more difficult. The velocity of the primary gaze shift will depend on multiple variables, like the eccentricity and modality of the stimulus. It will also differ from person to person. Also, the velocity of the moving gaze will most likely be much higher, for the eyes can rotate with a top speed of around 600 to 700 degrees per second, speeds you cannot obtain by passively rotating someone (at least not while guarantying their safety). This means that during active movement, the line projected by a visual stimulus on the retina should be a lot longer. This might in turn result in the brain being able to differentiate much easier between stimuli moving with the head and stationary targets in space.

1.7 Auditory stimuli

1.7.1 Auditory information and the visual map

Auditory information enters the brain through the ears where sound is transformed into electrical signals. Because the ears are fixed to the head and not to the eyes, a coordination transformation from head in space to eyes in space (auditory map to visual map) is required in order to make a correct gaze shift towards the target. To match the information from the ears to a location on the superior colliculus, the position of the eyes in head (E) has to be added to the incoming signal that only included the position of the head in space (H).

1.7.2 Localizing auditory stimuli

Because the ears have no equivalent to a retina of the eyes, determining the location of an auditory stimuli happens through different mechanisms. On the horizontal plane (the azimuth), the difference between the intensity and the difference in time between both ears is used to determine the location of the stimulus. The part of the stimulus that lies in the plane perpendicular to that of the ears (the elevation) is more difficult to localize. Through the shape of the ears the brain is capable of extracting this information [Goossens and Van Opstal, 1999].

1.7.3 Short duration auditory stimuli

Vliegen et al found that the brain is capable of accurately localizing an auditory target presented during active movement towards an earlier presented visual target, even for stimuli duration of $3ms$ Vliegen, Van Grootel, and Van Opstal, 2004. They concluded that 'The human auditory system adequately processes dynamically varying acoustic cues that result from self-initiated rapid head movements to construct a stable representation of the target in world coordinates.'

1.8 Focus of research

By focusing on stimuli of different duration in a dynamic double step experiment, we can test whether the results from the Van Barneveld et al experiments can be reproduced during active movement. Also including auditory and bimodal stimuli will give us the opportunity to look into the localization of these stimuli in this setup.

We will therefor use stimuli of different modalities and durations in a dynamic double step experiment to see if they can all be correctly localized. If the second stimulus in short duration visual trials is consequently localized in the wrong place, around G_C away from the actual location, we can conclude that also in active movement the brain is not able to incorporate the gaze correction in the localization of the second stimulus. If the stimuli of other modalities are correctly localized, we can conclude that the human brain is capable of incorporating the active movement for these modalities.

Chapter 2

Materials and Methods

2.1 Experimental setup

All experiments were performed in an acoustically shielded $3,6 * 3,6 * 3,6m$ room in complete darkness. All six walls inside were covered by pyramidal-shaped black acoustic foam plates which absorb sound frequencies above $500Hz$. The background noise was about $25dB$ sound pressure level (SPL).

2.1.1 Subjects

Three subjects (three males, age 20-25) were seated comfortably during the experiment in a chair with good back support. Viewing was always binocular.

2.1.2 Stimuli

All presented stimuli had durations of 4, 6, 10 or $30ms$. They were generated by the TDT (Tucker Davis Technologies) data acquisition and stimulus generation system. The experiments were run under Matlab (version R2013b) on a Windows PC connected to the TDT by a equipped zBUS interface card. The timing of the stimuli was controlled by the TDT. The primary stimuli where presented at 16 pre-determined locations in a sphere around the subject at a distance of $1,25m$ of the subject's head (figure 2.1). The stimuli where about 30 degrees apart of each other with the furthest locations 45 degrees from the subject's initial orientation on both the azimuth and elevation. The auditory stimuli consisted of band-pass-filtered ($500 - 20000Hz$) white noise, presented through Visaton SC5.9 speakers. All auditory stimuli had a SPL of about $65dB$ at the position of the subject's head. Visual targets were presented through LEDs at the same locations as the auditory stimuli.

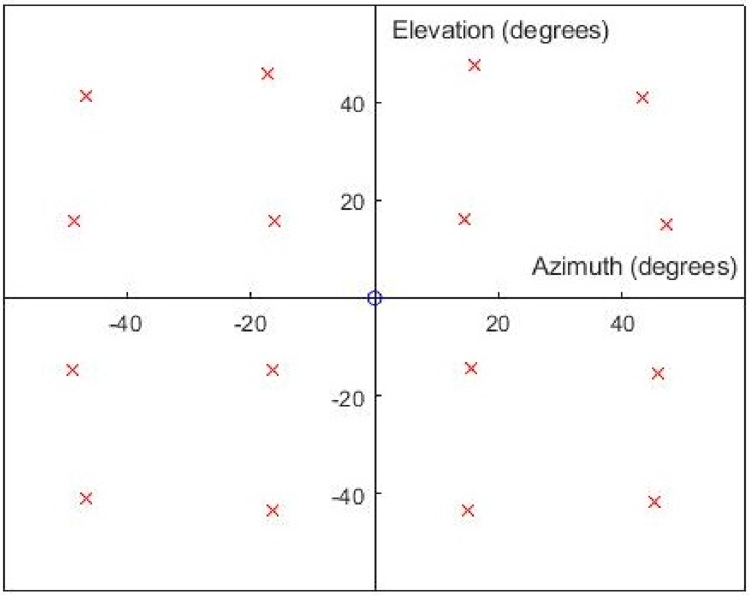

FIGURE 2.1: Possible locations of the first stimulus

2.1.3 Measurements

Head movements were measured by means of the search-coil technique [Collewijn, Van Der Mark, and Jansen, 1975]. A small search coil mounted on a helmet was worn on the subject's head. A $3*3*3m$ magnetic field was generated along the three cardinal directions by a Remmel-7 field generator at three different (pulsating) oscillation frequencies of 40, 60 and $80kHz$. The three oscillating induction voltages generated by the field in the small search coil are subsequently demodulated by the Remmel system and correspond to the sine of the angle of the coil's plane with the respective magnetic field. The Remmel system provides the average power (as a dc signal) from the coil at each of the three frequencies. After applying calibration, these voltages correspond to the head orientation in degrees.

Eye movements were measured by the pupil headset. The headset consisted of the frame of glasses with an attached infrared camera. The camera was pointed at the pupil and could detect what the direction of the pupil was in respect to the head [Kassner, Patera, and Bulling, 2014].

2.2 Calibration

2.2.1 Eye movement

Calibration of the pupil headset was done by seating the subject right in front of a computer screen. The subject was instructed to keep a distance of approximately $50cm$ from the screen. A visual stimulus was presented on the screen with which the subject was instructed to align his eyes without moving his head. This was done five times. Four of the stimuli were presented in the corners of the screen and a single one in the middle of the screen. After calibration, the information of the camera was transformed in eye in head coordinates in degrees.

2.2.2 Head movement

Attached to the helmet was a rod of about $30cm$ with a small fixation spot at its far end. Calibration of the head coil was done by letting the subjects subsequently turn their head to the location of 24 targets. At the target location, a LED was turned on. The subjects were asked to press a hand held button when the fixation spot was in line with the target. The known coordinates of the 24 targets could then be matched to the voltages in the search coils of the helmet by the Remmel system. A small off-line computer card (the Arduino) used labstreaming layer to synchronize the data from the head coil to that of the pupil headset.

2.3 Experimental paradigms

Subjects were asked to move and fixate their gaze to the presented stimuli as fast and accurate as possible without moving their body. They were instructed to fully complete the first saccade before making the second saccade. No further specific instructions were given regarding the speed or accuracy of the movements.

2.3.1 Experiments

Subjects were instructed to align their gaze with an initial LED at position $(0, 0)$. When ready, they had to press the hand held button. The initial LED would then be turned off and after a random interval of $300 - 800ms$, a stimulus of unknown modality and location (to the subject) was presented for the aforementioned duration of 4, 6, 10 or $30ms$. The stimuli were presented at a maximum eccentricity of 45 degrees in all directions. The subject was instructed to make a accurate and rapid head and eye saccade to the target.

During the saccade towards the first target, a second stimulus was presented. This was accomplished by a head trigger. The head trigger would send a signal to the computer when the head was moving with a preset velocity. The second stimulus would be presented for a fixed amount of time, equal to the first stimulus (4, 6, 10 or $30ms$). The modality of the second stimulus would also be the same as the first stimulus. The location would again be unknown to the subject. The locations were selected to make sure the second stimulus was not at the same location as the first stimulus or at the initial position $(0, 0)$. The maximum eccentricity of the second stimulus would be 60 degrees on the azimuth and 45 degrees in elevation from $(0, 0)$. This was done to make sure the subject was capable of perceiving the second stimulus since the head trigger would often be triggered when the gaze of the subject was only a few degrees away from the initial position.

Also, the second stimulus would be a maximum eccentricity of 45 degrees away from the first stimulus in all directions. Two seconds after the second target was presented, the initial LED was turned on again and the subject was told to align their fixation spot with the initial LED again.

2.4 Data analysis

2.4.1 Saccade detection

Saccades were detected off-line, on the basis of the calibrated signals, by a computer algorithm. The algorithm applied a set velocity criteria for saccade on- and offset (velocity threshold: 30 degrees/s, minimal duration: $10ms$) . Gaze saccades, head saccades and eye saccades were detected separately. Eye saccades were defined as the rapid eye movement of the eye relative to the head as detected by the pupil headset. The information from the head coil was used to detect the head saccades. The sum of the movement data from the pupil headset and the head coil was used to detect the gaze saccades. All detection markings were visually checked by the experimenter and could be interactively changed. This was done when the algorithm did not detect a saccade or when a saccade was detected where there was none.

2.4.2 Movement parameters

The algorithm extracted the initial and final positions of the gaze, head in space and eyes in head for every detected saccade. In this experiment, only the gaze data was used for the analysis. This information was combined with the information of the stimuli. From the stimulus data, the modality, duration and locations of both stimuli was used. For every individual trial, the saccade that came closest to the first stimulus was used to indicate the initial position from which the second stimulus was being localized. In the case of a trial with two saccades, this had to be the first saccade. However, in several trials there were more than two detected saccades. The final saccade of the trial was always used as the saccade that localized the second stimulus. The position before the first saccade (always very close to $(0,0)$) to the final location after the saccade that localized the first stimulus is defined as the total first saccade. From this position to the final location of the last saccade is defined as the total second saccade (figure 2.2).

Because we are interested in the localization of the second target, we wanted to be able to qualitatively compare all the different trials on the basis of this second localization. We can assume the head trigger is triggered somewhere on the path of the total first saccade. The second stimulus is therefor perceived by the subject during the movement towards the first stimulus. By rotating our coordinate system, we can always let this direction be positive along the x-axis (figure 2.3). Also, we can transpose our system to make the location we land on when localizing the first stimulus $(0,0)$. Doing this lets us easily compare our various trials. In this new dataset, the rotation and translation are included for later analysis (figure 2.4). From now on,

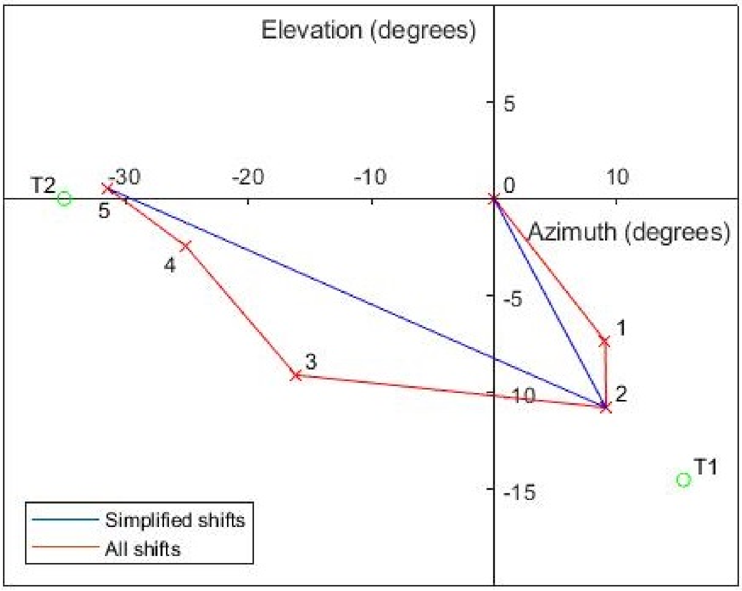

FIGURE 2.2: The red line through points $1-5$ shows the five individual saccades. The blue line simplifies this into two combinations of saccades, the first for localizing target 1 ($T1$) and the second for localizing target 2 ($T2$)

we will call the x-axis in this 'relative view' the parallel axis and the y-axis the perpendicular axis.

From this new representation of the data, we can look at the offset of the localization of the second stimulus in respect to the actual location of the second stimulus. A statistically relevant offset on the parallel axis could indicate there is something in the movement to the first stimulus influencing the localization of the second stimulus. A possible explanation for a positive offset (the parallel coordinate of the localization is generally larger than that of the stimulus) would be that the brain concludes the second stimulus is attached to the head during the movement to the first stimulus. For this explanation to be true, the positive offset should only be present (or at least larger) for short duration stimuli.

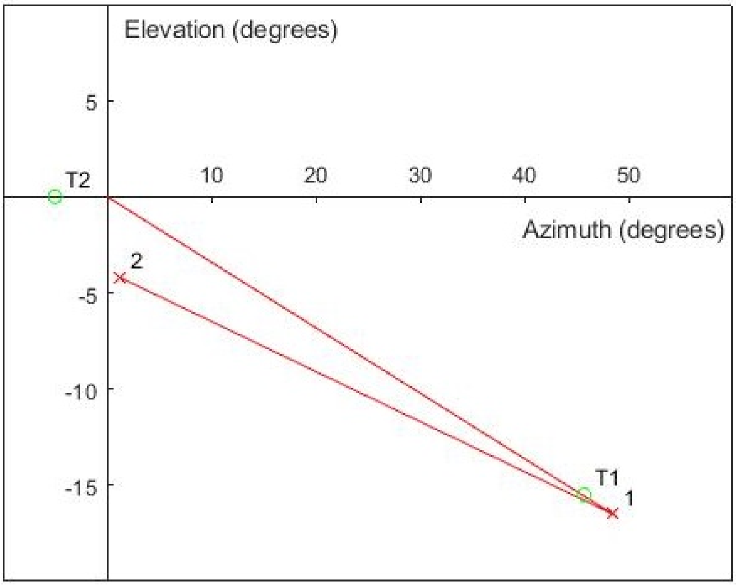

FIGURE 2.3: Original representation of a double localisation (single trial). The red line indicates the saccades, going from $(0,0)$ to 1 and then from 1 to 2. $T1$ and $T2$ are the corresponding targets.

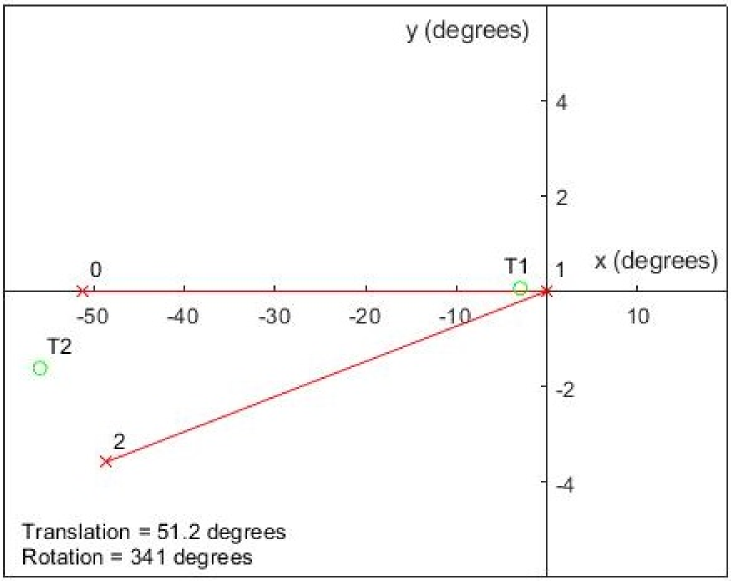

FIGURE 2.4: Representation of a single trial in relative view. Location 1 (where the localization of the first target $T1$ finished) is moved to $(0,0)$ and the plot is rotated so that the direction of the movement to location 1 is positive on the x-axis. In the bottom left you can see how much the plot was shifted (translated) and rotated.

2.4.3 Statistics

Only trials that yielded at least two saccades were used for the analysis. If the localization of the first stimulus was very inaccurate (more that 30

degrees off), the trial was also excluded. We used linear regression to analyze the localization as a function of stimulus location. A plot with linear fit was made for every combination of modality and duration on both the azimuth and elevation. This was done for the first target, second target in world view and second target in relative view. All the figures can be found in B. In total, 2092 measurements were analyzed, divided over the different durations and modalities as shown in table 2.1

Modality	**4 ms**	**6 ms**	**10 ms**	**30 ms**
Light	168	172	182	187
Sound	152	171	167	163
Bimodal	184	176	183	187

TABLE 2.1: Number of measurements analyzed for every combination of modality and duration

Chapter 3

Results

After the data analysis we can sort the data into three categories: First localization, second localization in world view (before the rotation and translation) and second localization in relative view (after rotation and translation). We will start by analyzing the first localization. This will give us a frame of reference with which we can compare the second localization. The relative view data will be used lastly.

3.1 First stimulus

In figure 3.1 we see a visual representation of the first localization on the azimuth and elevation for the three different modalities. In this figure, the different durations have been combined because there were no significant differences between them (Appendix B, figures B.1 and B.2). The localization on the azimuth was pretty precise, especially for the light and bimodal targets. The linear fit shows that there was almost no average undershoot (when the gaze landed short of the target) or overshoot (when the gaze went too far) in them. (both an average shortage of less than 1.5 degrees). The auditory stimuli had a slight average overshoot in the localization on the azimuth of about 2 degrees (table 3.1). This can also be derived from figure 3.1 by looking at the steepness of the fit.

In elevation, all figures show a average undershoot (light: $1-3$ degrees, auditory: $8-10$ degrees, bimodal: $4-6$ degrees, table 3.2). The undershoot for the auditory stimuli with a negative elevation was considerably higher than for the stimuli with a positive elevation. This can be concluded from the second number of the fit in figure 3.1 (-5.9293 for the auditory elevation plot). The linear fit through the auditory elevation plot is also considerably less accurate than with any of the other plots, as shown by the low R^2 value. This indicates that the localization was also less consistent, meaning there was a lot of variation between different trials.

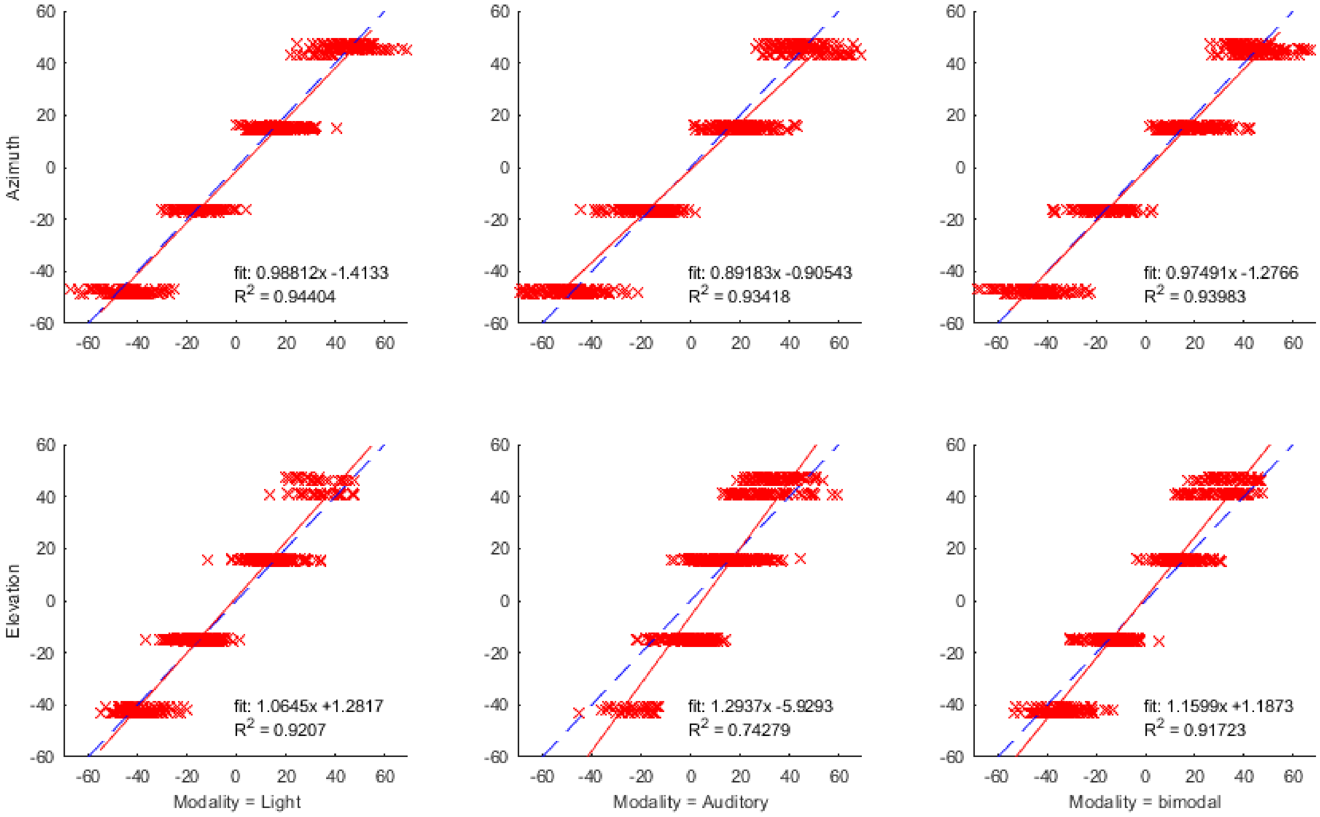

FIGURE 3.1: Localization of the first stimulus on the azimuth and in elevation. On the y-axis is the stimulus position and on the x-axis the corresponding localization (both measured in degrees). If a stimulus is localized at its exact location, an 'x' will appear on the dashed blue line. The R^2 is a measure of precision on the linear fit through the measurements.

Modality	**4 ms**	**6 ms**	**10 ms**	**30 ms**
Light	2.108	0.658	0.680	1.609
Sound	−1.548	−2.820	−2.401	−1.939
Bimodal	1.274	0.422	0.1725	0.233

TABLE 3.1: Average undershoot on the azimuth for the first localization

Modality	**4 ms**	**6 ms**	**10 ms**	**30 ms**
Light	2.432	1.589	2.674	3.079
Sound	10.074	9.837	9.884	8.639
Bimodal	4.658	5.325	5.223	4.238

TABLE 3.2: Average undershoot in elevation for the first localization

3.2 Second stimulus in world view

As can be seen in appendix B, figures B.3 and B.4, the second localization was also accurate. It is clearly visible that in most cases it was still possible to observe the stimuli and localize them accordingly. On both the azimuth and elevation, all combinations of modality and duration have at least a slight undershoot (tables 3.3 and 3.4). The fit through the measurements is accurate (R^2 larger than 0.8) for almost all combinations of modality and duration.

The only exceptions are the auditory elevation plots. The R^2 values of these are much lower than those of the other trials, between 0.4 and 0.6. This means the localization in elevation for the auditory stimuli was a lot less accurate and consistent. Like in the first localization, the second value of the fit was also exceptionally low (between -9 and -11 for all durations). This means there was a large difference between localizing stimuli with a positive and negative elevation. However, a slight correlation between the stimulus location and the localization is still visible, meaning the subjects were able to localize the auditory stimuli even in elevation up to a certain degree.

Modality	**4 ms**	**6 ms**	**10 ms**	**30 ms**
Light	3.389	3.680	4.176	3.891
Sound	3.597	3.252	1.880	2.672
Bimodal	2.006	2.708	2.831	3.372

TABLE 3.3: Average undershoot on the azimuth for the second localization

Modality	**4 ms**	**6 ms**	**10 ms**	**30 ms**
Light	4.772	5.030	3.630	4.867
Sound	13.331	11.387	11.105	9.210
Bimodal	3.102	4.085	4.266	3.789

TABLE 3.4: Average undershoot in elevation for the second localization

Targets with a larger eccentricity yielded a higher average error in their localization than targets with a lower eccentricity (table 3.5). The second target had lower eccentricity than the first target (on average) and the associated localization had a larger error. Therefor, the second localization was less accurate for all modalities and durations.

	Light	**Auditory**	**Bimodal**
FT average eccentricity	38.7	40.4	41.5
ST average eccentricity	34.4	35.2	32.9
FT localization error	9.144	15.576	10.577
ST localization error	10.233	17.742	8.949
FT low eccentricity error	7.636	13.276	7.561
ST low eccentricity error	8.185	14.281	7.253
FT high eccentricity error	10.325	17.102	12.233
ST high eccentricity error	11.364	19.254	10.036
FT relative error	26.3	43.0	27.3
ST relative error	34.1	53.4	32.2

TABLE 3.5: Average eccentricity and localization error of both the first and second localization for all different modalities. FT means First target and ST means second target. Low eccentricity means the target was less than 25 degrees away from where the saccade was initiated. High eccentricity means the target was more than 25 degrees away. The relative error gives the error as a percentage of the eccentricity.

3.3 Second stimulus in relative view

3.3.1 Localization offset on the parallel axis

The rotation and translation of the data allows us to evaluate the possibility of the brain not including the gaze correction for short duration stimuli (Materials and methods; Movement parameters). This would lead to a positive offset on the parallel axis. The data shows a positive offset for all durations and modalities (table 3.6). The offset for short duration stimuli is not larger than that of longer stimuli. The differences between the modalities are larger than the differences between the durations. This means that not including the gaze correction is not a plausible explanation for this offset. The auditory stimuli have the largest offset, followed by the light and then the bimodal stimuli.

Modality	**4 ms**	**6 ms**	**10 ms**	**30 ms**
Light	5.208	5.247	4.972	5.021
Sound	6.193	6.336	6.662	6.262
Bimodal	2.682	2.934	3.354	3.245

TABLE 3.6: Offset on the parallel axis in degrees. A positive number means the location on the parallel axis of the localization was larger than that of the stimulus (on average).

3.3.2 Distance to the second stimulus

The omnipresent positive offset in the second localization could be explained by an average offset of the second stimuli on the parallel axis. In table 3.7, we see that there is a large negative offset on the parallel axis. This can also be noticed in figure B.5 in B. This negative offset means the subject had to move back in the direction it came when localizing the first stimulus to localize the second one. In figures 3.3 and 3.4 in B, we can see that the fit always had a steepness larger than one. This means the subjects fell short in their localization more often than they went too far. Combined with the average negative offset on the parallel axis of the second target, this could explain the positive offset of the parallel localization of the second stimulus.

Modality	**4 ms**	**6 ms**	**10 ms**	**30 ms**
Light	-21.0	-21.3	-19.7	-20.4
Sound	-24.0	-24.6	-21.7	-22.1
Bimodal	-18.8	-19.6	-21.5	-20.0

TABLE 3.7: Average offset of the second stimulus on the parallel axis. A positive number means the subject had to move further on the parallel axis to correctly localize the second stimulus.

Chapter 4

Discussion

4.1 Summary

We investigated saccadic eye and head movement towards short duration targets presented during active movement. The results showed that there was no significant difference between localizing the short ($4ms$) duration stimuli from the long ($30ms$) stimuli. There was a difference between the modalities. Bimodal stimuli could be localized a little more precise than visual stimuli and the auditory stimuli were the least accurate. In all cases, the subjects could extract enough information from all different stimulus types to correctly localize the target.

4.2 Related studies

The results of this experiment support the results of Vliegen et al. (2005) who concluded that localization remains accurate in dynamic double steps. Complementary to the Vliegen et al. study, we conclude that stimuli of different modalities (auditory and bimodal) also remain accurate during dynamic double steps. In active movement, even stimuli of durations as short as $4ms$ can be localized during dynamic double steps.

Van Barnefeld et al. (2011) showed that subjects who are being moved passively and are presented with a short duration (0.5 or $4ms$) visual stimulus could not correctly localize the stimulus. The brain seemed to conclude that the stimulus was rotating with the same speed as the head of the subject instead of being fixed in space. For visual stimuli of a long duration ($100ms$) the subjects were able to differentiate between stimuli moving with the head and stimuli fixed in space.

This raises the question why these results are so different. In the Van Barneveld et al. experiment, they concluded that the relative motion of the target on the retina of the subject played an important role. A target presented for a longer amount of time will create a line on the retina of the subject, while a shorter target creates something that looks more like a dot (see Appendix A). This line gives the brain the information that the subject is moving in respect to the subject while a dot does not. A possible explanation is therefor that the subject could be moving faster during active movement. Faster movement would mean that even a short duration target could create a line on the retina. Because our shortest duration stimulus was presented for $4ms$, it could be that even this stimulus created a long enough line on the retina for the brain to conclude that the target was moving relative to the gaze.

A second explanation could be that during active movement, the brain is aware of the body's movement. If this is the case, it wouldn't need the information from the retina. The brain could automatically conclude the target is stationary in space and make a correct shift towards the target. To differentiate between these two possible explanations, more testing with extremely short duration stimuli is needed. These stimuli must be short enough to create a dot on the retina instead of a line to differentiate between these two solutions.

4.3 Limitations and improvements

Technical issues came up several times during this research. Problems with the pupil-tracking during high eccentricity saccades, static in the head measurements and issues with the programming of the LEDs were eventually fixed, but some other problems could not be solved. The reason this research had no trials with a duration of under $4ms$, was that it was impossible to create those with the used setup.

Another improvement that can be made in future research is in the selection criteria of locations for the second stimulus. In this research, the average negative offset of the second stimulus on the parallel axis (Chapter Results, section 3.3.2, Distance to the second stimulus) resulted in an offset in its localization. This error was the same kind of error as we were trying to measure and it therefor conflicted with the analysis. Making sure their is no relative offset in the second target could definitely aid the analysis.

Lastly, there were only three subjects who participated in this research. All of them were young adult males. Having a larger and more varied group of subjects might increase the statistical relevance of the research.

4.4 Conclusion

Despite it's limitations, this research can serve as a stepping stone for further research regarding double-step localization. Fixing the aforementioned limitations might result in a solid basis for a research into the possible inability to correctly localize extremely short duration stimuli during active movement. Transforming the data from the world view representation into the relative view representation (Chapter Materials and Methods, section 2.4.2 Movement parameters) created a insightful way to detect an average offset on the parallel axis.

Appendix A

Projections on the retina

When a visual stimulus is presented, it creates a projection on the retina of the eye. The size of the projection can be calculated if the size of the object (V), the distance of the object to the eye (v) and the distance from the lens of the eye to the retina (V, the diameter of the eye) are known. The formula to calculate the size of the projection on the retina is then:

$$B = \frac{b * V}{v} \tag{A.1}$$

In the case of this study, the LED had a diameter of about $3mm$, the distance from the LED to the eye was $1.5m$ and the diameter of the average human eye is $24 \pm 0.3mm$ [Bekerman, Gottlieb, and Vaiman, 2014]. This gives us a circular projection on the retina with a diameter of $48\mu m$.

During relative movement of a stimulus in respect to the gaze, the projection is moving across the retina. This creates a line on the retina. The length of the line on the retina can be calculated if the relative speed of the object in respect to the gaze (v_{rel}) in degrees per second, the time the stimulus was presented (t) and the diameter of the eye (V) are known.

$$l = \frac{v_{rel} * \pi}{180} * V * t \tag{A.2}$$

The diameter of the eye is a constant, while the time the stimulus is presented and the relative speed of the stimulus can vary. In table A.1 the length of the line is calculated for different stimulus duration and speeds.

v_{rel} (degrees per second)	$0.5ms$	$4ms$	$100ms$
50	$0.010mm$	$0.083mm$	$2.09mm$
300	$0.063mm$	$0.50mm$	$12.6mm$

TABLE A.1: Length of the line on the retina for different stimulus duration and speed

Combining the length of the line and the size of the projection on the retina gives us an idea of what the shape on the retina looks like (figure A.1). In the Barneveld et al. (2011) study, they had a relative speed of 50 degrees per second and a stimulus duration of 0.5 or $4ms$. These correspond to the first two shapes in figure A.1. During active movement, the relative speed is often much higher. With a speed of 300 degrees per second and a stimulus duration of $4ms$, the projection on the retina will have a shape that resembles the bottom shape of figure A.1.

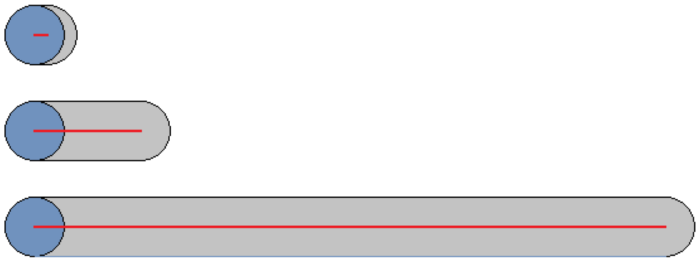

FIGURE A.1: Projections on retina for 3 different stimulus duration and speed

Due to imperfections in the lens of the eye, the projection on the retina might be more blurred than in the representation of figure A.1. This would mean the projection of the shape might seem bigger than the $48\mu m$ we calculated earlier. Taking this into account, it is plausible that the brain interprets the smaller shapes as created by a single, somewhat elliptical shape that is moving in the same direction and with the same speed as the gaze. The shape produced by stimuli with a longer duration or a higher relative velocity could more easily be used to determine that they are moving in respect to the gaze.

Appendix B

Additional figures

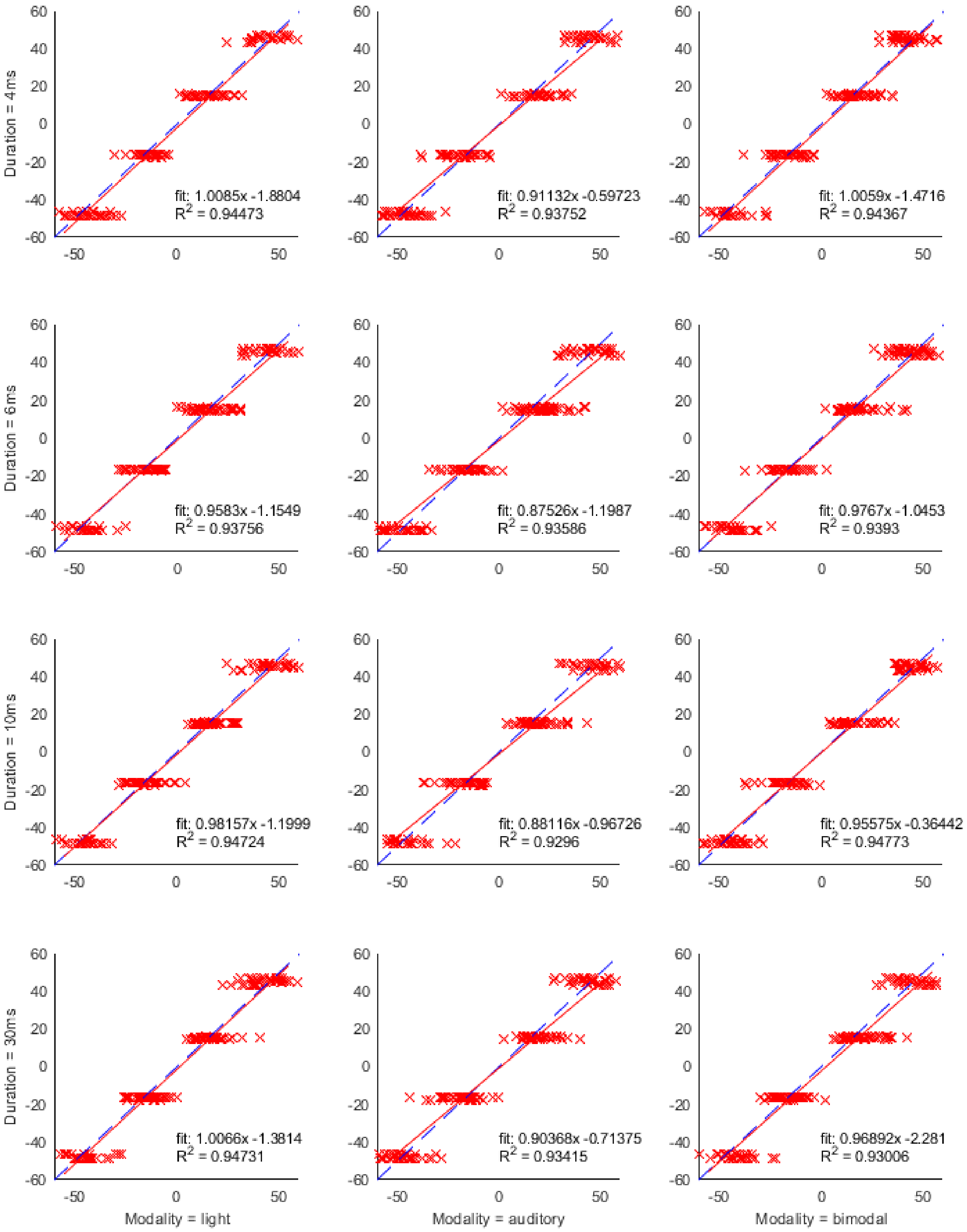

FIGURE B.1: Localization of the first stimulus on the azimuth. On the y-axis is the stimulus position and on the x-axis we have the corresponding localization. If a stimulus is located perfectly, an 'x' will appear on the dashed blue line. The R^2 is a measure of precision on the linear fit through the measurements.

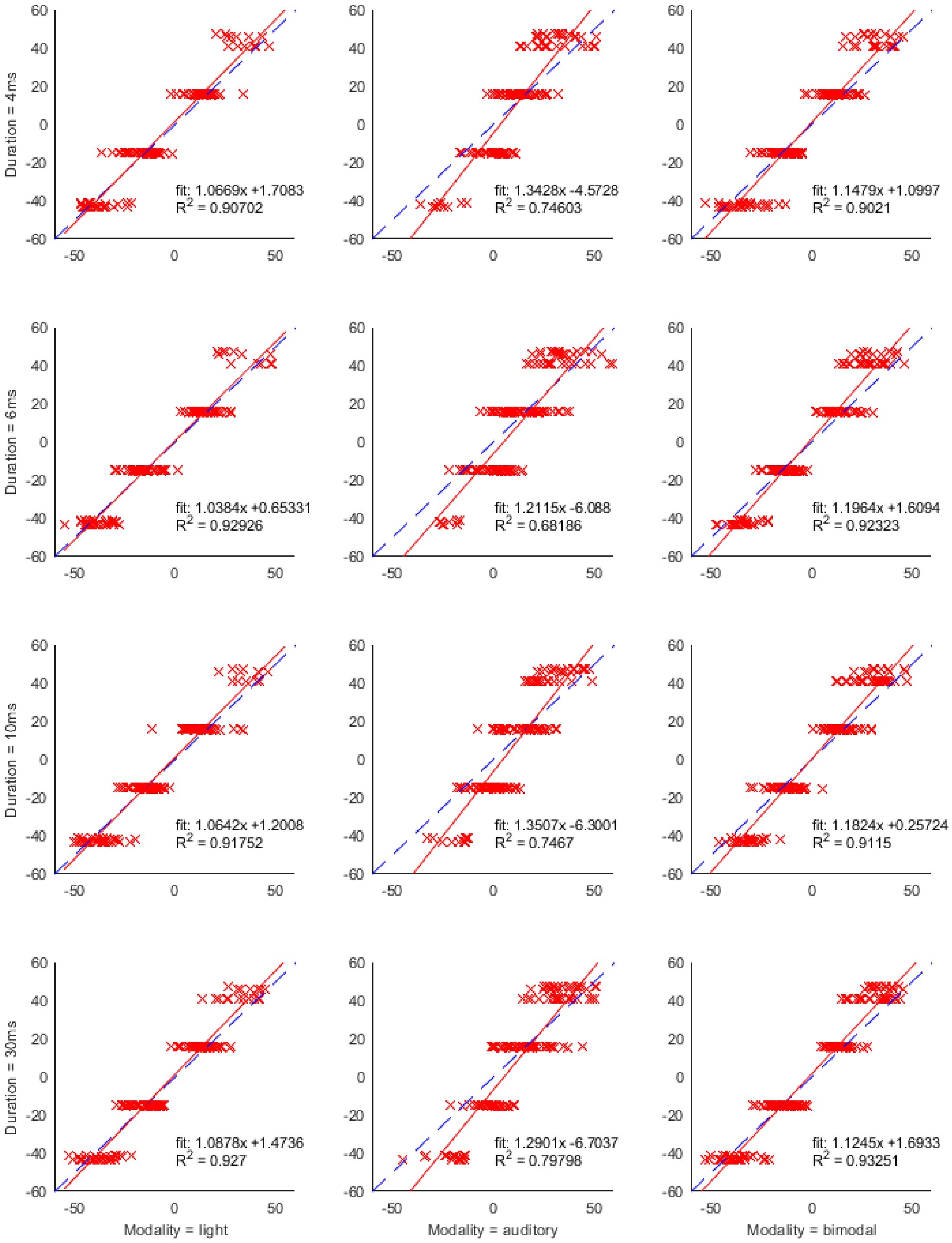

FIGURE B.2: Localization of the first stimulus in elevation. On the y-axis is the stimulus position and on the x-axis we have the corresponding localization. If a stimulus is located perfectly, an 'x' will appear on the dashed blue line. The R^2 is a measure of precision on the linear fit through the measurements.

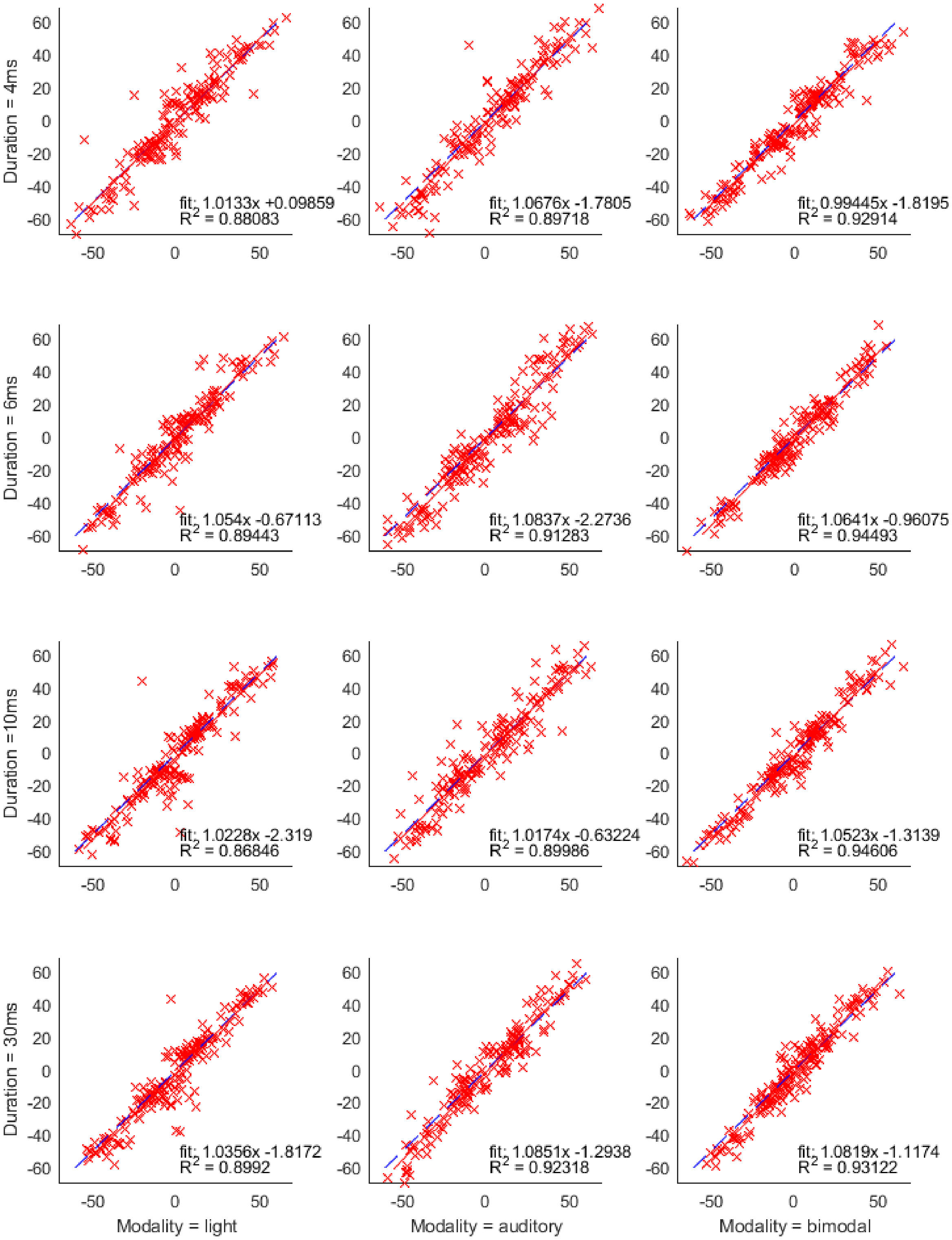

FIGURE B.3: Localization of the second stimulus on the azimuth. On the y-axis is the stimulus position and on the x-axis we have the corresponding localization. If a stimulus is located perfectly, an 'x' will appear on the dashed blue line. The R^2 is a measure of precision on the linear fit through the measurements.

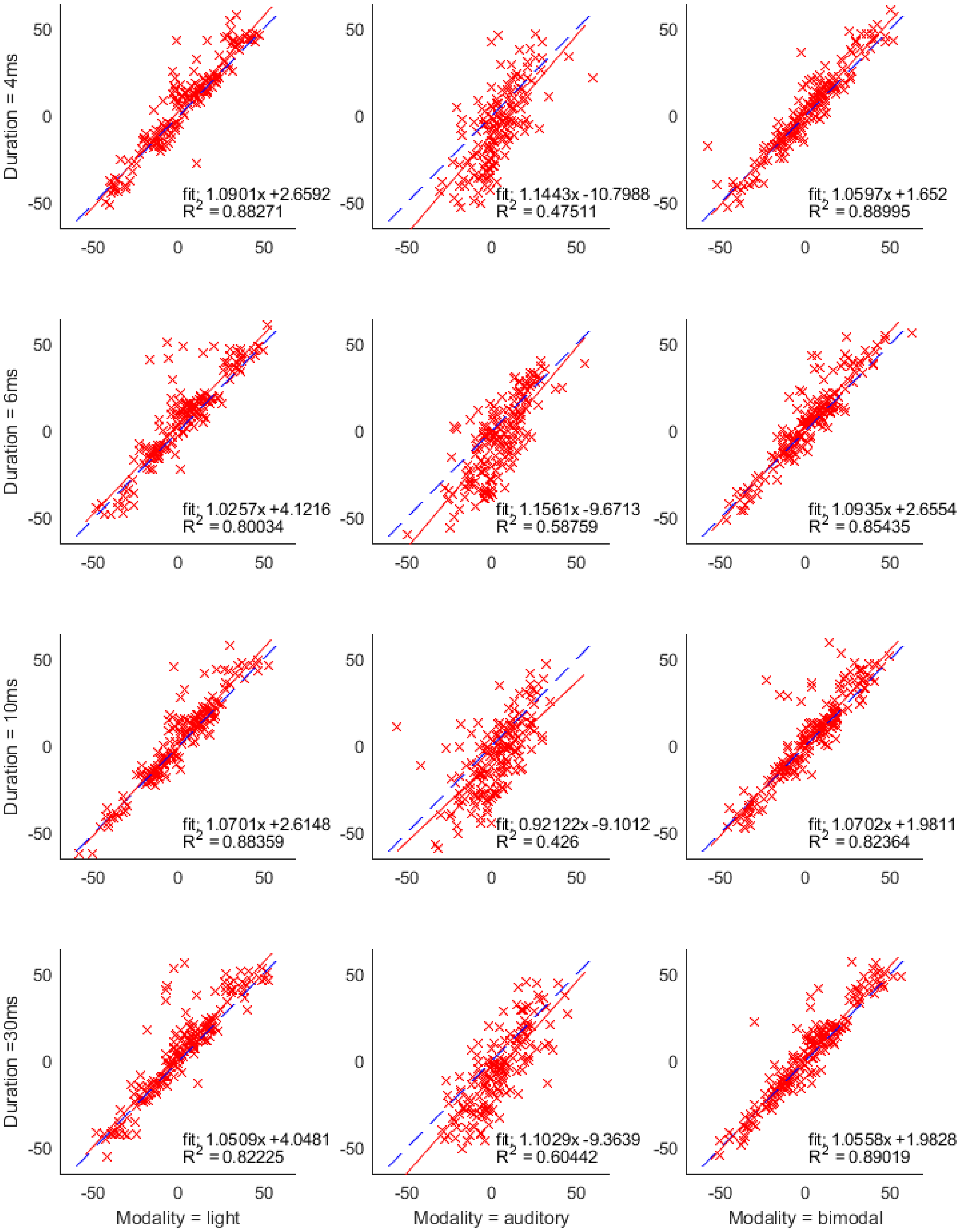

FIGURE B.4: Localization of the second stimulus in elevation. On the y-axis is the stimulus position and on the x-axis we have the corresponding localization. If a stimulus is located perfectly, an 'x' will appear on the dashed blue line. The R^2 is a measure of precision on the linear fit through the measurements.

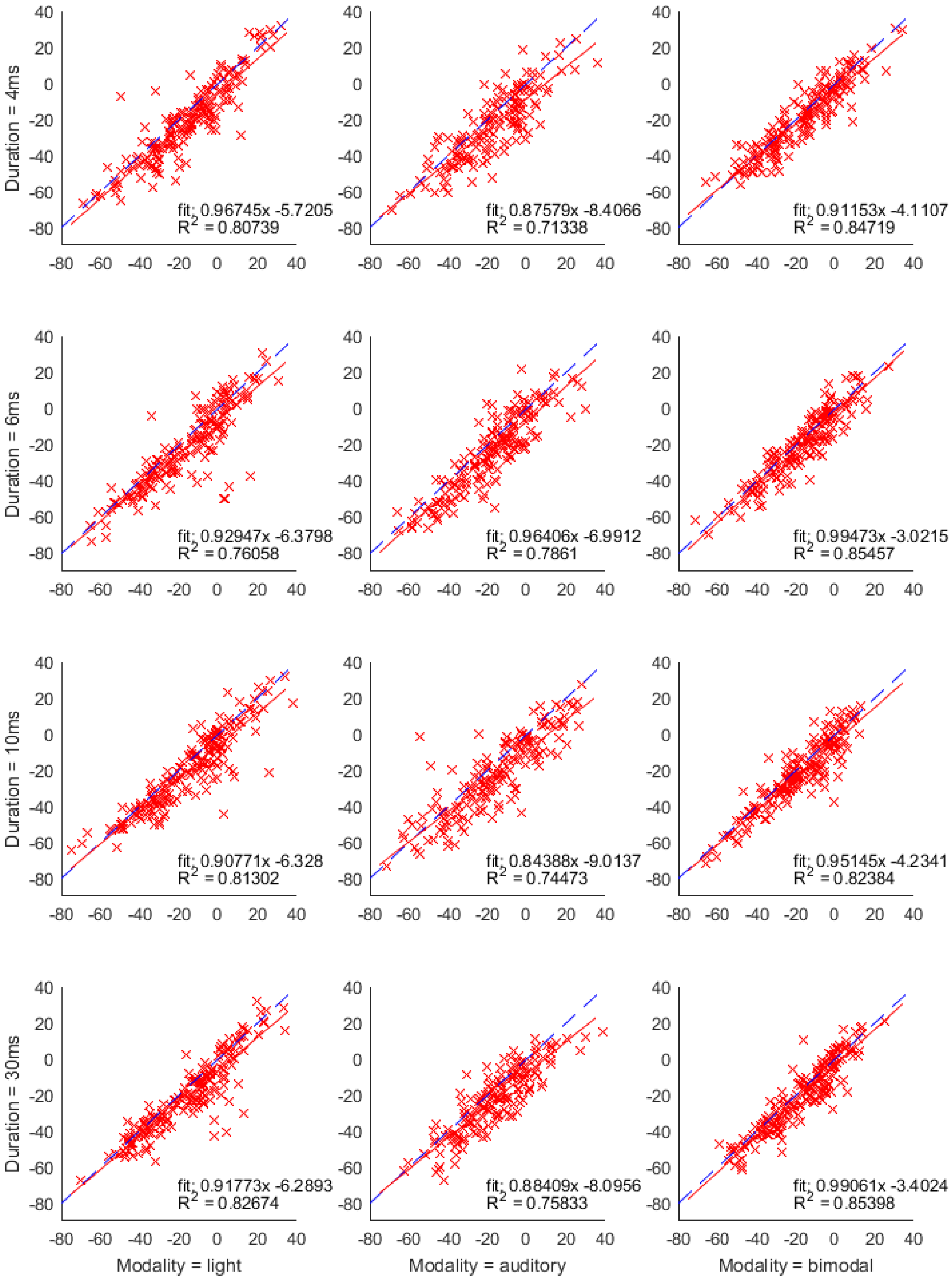

FIGURE B.5: Localization of the second stimulus on the plane parallel to the initial movement towards the first stimulus. On the y-axis is the stimulus position and on the x-axis we have the corresponding localization. If a stimulus is located perfectly, an 'x' will appear on the dashed blue line. The R^2 is a measure of precision on the linear fit through the measurements.

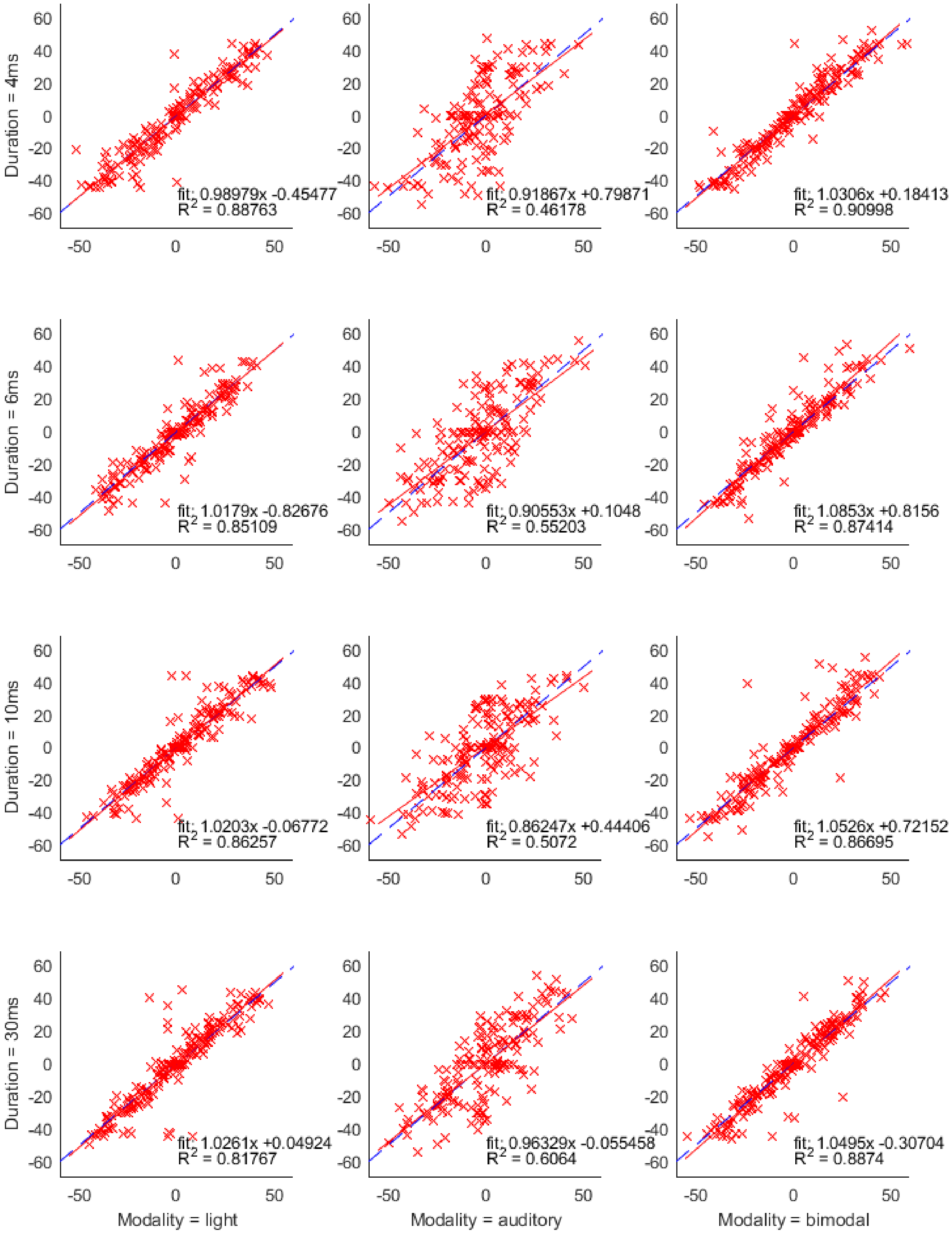

FIGURE B.6: Localization of the second stimulus on the plane perpendicular to the initial movement towards the first stimulus. On the y-axis is the stimulus position and on the x-axis we have the corresponding localization. If a stimulus is located perfectly, an 'x' will appear on the dashed blue line. The R^2 is a measure of precision on the linear fit through the measurements.

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