**\chapter{Audio-Visual experiment - relations between the modalities}**

**\label{chap:VisalAuditoryExp}**

**\section{Methods}** **\label{sec:AVMethods}**

**\subsection{Experiment Procedure}**

**\label{subsec:AudioVisualexp}**

**\subsubsection{General}**

%\paragraph{}

Combined audio-visual experiments were conducted to evaluate the dynamical influence of one perception on the other.

The experiments investigated relations between detection performance in two modalities under different contextual relations with the perceived object.

%, while the temporal structures of the input in all sessions are identical.

%\paragraph{Experiment setting}

Each subject sat in front of a computer screen in a dark room wearing headphones.

Consecutive combined trials were applied; each trial included background stimuli in both modalities concomitantly, but only in one (random) modality was a stimulus actually delivered upon the background.

Subjects were asked to respond with a key press:

pressing '1' for noticing either stimulus or '0' when neither auditory nor visual stimulus was noticed.

Responses were identical with respect to seeing or hearing; consequently, subjects were not required to classify the type of stimulus.

There were 24 subjects (13 females), aged 21-32, that participated in the experiment.

All subjects had regular or corrected-to-regular vision, regular hearing, and were not diagnosed as having attention deficit disorders; in addition, all them were naive to the purpose of the experiment.

Subjects also signed a consent form and were paid for their time.

There were 3 subjects (3 females) excluded from results for having 15\% or more false positive responses to sham trials, and

2 more subjects (1 female) were also excluded because of an extreme difference in performance between the different sessions (details in~\ref{subsec:TotalDP\_OL-CL}).

**\subsubsection{Visual stimulus}**

The visual stimulus was the same as in the visual experiment that is described in detail in section~\ref{subsubsec:VisualStim} and is shown in figure~\ref{fig:ExperiemntStim}.

**\subsubsection{Auditory stimulus}**

The auditory stimulus was a beep embedded in a noise.

The background was a white noise, bandpass filtered to the range between 800-1200 Hz, for a duration of 2 seconds.

The beep was a 1000-Hz pure tone of 0.2 seconds long, which an example is shown in figure~\ref{fig:AuditoryStim}.

The delay of the beep from the beginning of the background noise was randomly selected in every trial out of three options: 0.75, 1, or 1.25 seconds.

The background noise level was kept constant throughout the experiment, while beep levels were changed between trials.

For the rest of the document, the term *auditory level* refers to the ratio between the beep energy and the total energy (beep+noise) in the same period.

\begin{figure}[H]

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{**\includegraphics**[scale=0.3]{./graphics/ExperiemntAVStim/AuditorySimSpectralTemporal.jpg}}

\caption[\textbf{Auditory stimulus}]{\textbf{Auditory stimulus}

Background noise lasts 2 seconds and the beep, which is embedded in it, is 0.2 seconds long.

In this example, the beep started 0.75 seconds after the beginning of the noise.

\newline The upper panel shows a frequency-temporal decomposition of one trial.

Background noise ranges from 800 Hz to 1200 Hz, and the beep is played at exactly 1000 Hz.

\newline The lower panel shows the total energy of the signal.

In this example, the auditory level is 0.2 (see previous paragraph for definition of auditory level).

Although the beep is hard to notice in the signal in the trace (marked with an orange rectangle), this level makes a very clear *beep* when it is heard.

.**\label{fig:AuditoryStim}**}

\end{figure}

**\subsubsection{Audio-Visual combined trial structure}**

Each trial was composed of three stages.

A timeline that is presenting one audio-visual trial is shown in figure \ref{fig:CombinedStim}.

\begin{itemize}

\setlength\itemsep{0em}

\item\textbf{A reset period} of 0.75 seconds contains the auditory background and a blank rectangle with a central fixation circle for the visual reset.

\item\textbf{A stimulus period} of 0.75 seconds is when concomitant visual \& auditory backgrounds are presented: noise and a visual black \& white dotted image, respectively.

Only in one modality, either the auditory or the visual, is a stimulus presented on top of the background during this period.

\item\textbf{A response period} is the final stage where an auditory background noise continues for 0.5 seconds (to a total of 2 seconds) and is followed by silence.

While the visual reset screen is displayed,

this state continues for an unlimited duration while the system is waiting for the subject to respond.

\end{itemize}

Once the subject responds, the next trial begins.

\begin{figure}[H]

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**\includegraphics**[scale=0.35]{./graphics/ExperiemntAVStim/CombinedStim3.jpg}}

\caption[\textbf{Audio-Visual trial}]{\textbf{Audio-Visual trial}

The trial begins with a background noise and a background white image.

The stimulus period, in which the visual background (with/without spot) is shown, is noted with a red line on the timeline.

This is also the range of time in which the auditory beep may begin.

In this example, the beep starts 1 second after the beginning of the trial.

\newline For demonstration, both beep and spot are shown on top on the background, while in the actual experiment, only one of them is presented in any trial.

**\label{fig:CombinedStim}**}

\end{figure}

**\subsubsection{Experiment structure and closed loop procedure}**

**\paragraph**{}

The experiment consisted of 4 sessions of 300 consecutive combined trials.

In every trial, the modality of the stimulus was randomly chosen.

Sham trials, in which no stimulus was presented in any modality, were randomly admixed.

Some subjects (n=7) had 30 sham trials, while the rest (n=17) had 10 sham trials per session.

In every session, each modality was presented with 135-145 stimuli.

The difference between sessions was the type of the relations between the input levels (of either modality) to the subject responses.

For each subject, the first session was a session where both modalities had \textbf{closed-loop} (CL) relations between inputs and the responses.

The closed-loop procedure was adapted from the principle to voltage clamp, and was demonstrated in visual psychophysical setting in the work by Marom \& Wallach in 2011~\cite{Marom2011}.

Closed loop (CL) relations mean that inputs are adjusted according to the previous responses.

For each modality, filtering controller tracked responses of relevant stimuli and created a measure of the \textit{momentary detection probability (DP)}.

When the DP was higher than 0.5 (the *clamp level*), the following stimulus level was lower than the previous one, which resulted with a more difficult stimuli for the subject to detect (lower contrast, or lower power of beep),

It was the opposite when DP declined below this level.

Detailed description of the controller, its parameters, and the momentary DP calculation are found in Methods~\ref{sec:AVMethods}, equations~\ref{eq:DPfilter} to~\ref{eq:PID}.

The first session was marked VCL\\_ACL (Visual CL - Auditory CL) i.e., each modality had an independent close-loop controller that determined the level of its input stimuli.

A different type of session was an open loop (OL) session where no relations between the subject responses and the input levels existed.

Instead, the input levels were \textbf{Replayed} (RE) in the same order as they were in the first session, such that statistics of inputs and the temporal structure were almost identical to those of the first session.

The only difference was that there were new random admixture of sham trials among the trials.

This session was marked VRE\\_ARE (visual replay - auditory replay).

The other 2 sessions were mixed such that one modality's inputs were controlled in CL, and the inputs of the other were replayed (OL) from the first VCL\\_ACL session

These mixed sessions were marked VCL\\_ARE and VRE\\_ACL.

For every subject, the first session was always VCL\\_ACL, and the order of 3 other sessions were randomly shuffled between subjects.

VCL\\_ACL session was 25 trials longer, and the first 25 trials were used only for stabilizing the controllers and were not replayed in subsequent sessions, and they were not included in the analysis.

**\subsection{Technical Details}** **\label{sec:AVTechnicalDetails}**

**\subsubsection{Closed Loop: PID controller}**

**\label{subsubsec:CLThechDetails}**

Closing a loop on response is effectively a process of on-going adjustment of stimuli levels according to the momentary DP.

The purpose of this adjustment is to flatten response fluctuations such that the DP stays as close as possible to a desired value, which is the clamped level (in our experiments, it is 0.5 DP).

\newline For the estimation of DP, we apply a smoothing exponential filter on past responses.

There is a separate controller for each of the modalities, which updates only according to responses to stimuli of the same modality.

DP estimation is performed by applying an exponential filter on responses.

It is given by the following formula:

\begin{flalign}

**\label{eq:DPfilter}**

DP\_{n}={(1-e^{-\frac{1}{\tau}})}\*Response\_n + (e^{-\frac{1}{\tau}})\*DP\_{n-1}

\end{flalign}

The error to be minimized is the distance of the DP from 0.5:

\begin{flalign}

**\label{eq:err}**

err\_n=0.5-DP\_{n-1}

\end{flalign}

Note that $err\_n$ can be either positive or negative with respect to the size of DP.

Next, the input level is determined by a Proportional-Integral-Differential controller, which is implemented in the following manner:

\begin{align}\**label{eq:PID}**

x\_{n+1}=x\_0 + (err\_n)\*P + (\sum\_{i=1}^{n}err\_i)\*I + (err\_n-err\_{n-1})\* D

\end{align}

Specifically, for this experiment, we used the following constants:$ ~P=0.2,~~I=0.02,~~D=0.002,~~x\_0V=0.7,~~x\_0A=0.2$

\newline Note that visual level and auditory level refer to different qualities, and each of them has an individual initial level: $x\_0V$ for visual and $lx\_0A$ for the auditory stimuli.

**\subsubsection{Detection probability calculation}**

**\label{subsubsec:DPcalc}**

The calculation of ongoing DP was performed separately for each modality.

Responses were divided by the modality of the stimulus, while the original time of responses were kept constant to maintain time synchronization of the two modality traces.

When DP was estimated in post processing, we used the same filter that was used in the CL session (equation~\ref{eq:DPfilter}).

To avoid the transient period of controller stabilization, the first 25 responses of all sessions were precluded from further analysis in all sessions (in addition to the first 25 trials in VCL\\_ACL session that were not replayed).

\begin{figure}[H]

\centering{

**\includegraphics**[scale=0.73,trim={1.67cm 0.5cm 0 0},clip]{./graphics/Fluctuations/DPcalcEx\_DR\_M\_32.png}}

\caption[\textbf{DP Calculation Example}]{\textbf{DP Calculation Example}

Top panel: all responses, red circles for visual and blue circles for auditory stimuli.

In the two lower panels, the responses are separated by the modality of the stimulus.

Solid bold lines show the filtered values, which represent the momentary DP of each modality (upper, Red for visual; lower, Blue for auditory).

**\label{fig:DPculcExample}**}

\end{figure}

**\section{Results}**

**\label{sec:Results}**

The current experiment was examined in four ways:

Initially, we compared the global measures of performance among sessions.

Second, for each modality, we tested how the regime of the counter affects the fluctuations of the first.

Third, we investigated the temporal relationship between the modalities.

Lastly, we investigated whether a recency effect occurs within and/or between the modalities.

**\subsection{Total rate of detection in closed and open loop does not change}**

**\label{subsec:TotalDP\_OL-CL}**

To establish foundations for the comparison between the experiment modes, we compared the performance between them.

We found that the total rate of detection on average did not alter whenever subjects performed the task in OL or CL, as seen in figure~\ref{fig:TotalDP}.

It is expected that all subjects in CL had around 0.5 detection rate, since the CL controller ensures this state.

In OL, for the specific subjects, the total rate in OL was higher or lower than 0.5.

However, across all subjects on average, the positive responses were also around 0.5.

Two subjects were excluded from the rest of the analysis, since they had an overall detection rate (in at least one OL session) that deviated extremely from 0.5.

Specifically, the deviation was more than 2$\sigma$ from the mean detection rate of all subjects.

\begin{figure}[H]

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**\includegraphics**[scale=0.6,trim={1cm 0 0 0},clip]{./graphics/TotalDP/TotalDP.png}}

\caption[\textbf{Total detection rate}]{\textbf{Total detection rate} is on average the same in all four sessions.

On the left, in red, the total portion of positive responses of visual stimuli is presented.

Performance of individual subjects are marked with dots.

The red area stands for the STD around the mean of the subjects, the thin lines represents the confidence level of 95\%, and the white circle is the median.

On the right, in blue, the same marking for auditory responses is presented, which the 2 subjects that had extreme results are marked with an 'x'.

**\label{fig:TotalDP}**}

\end{figure}

\newpage

**\subsection{Response fluctuations in closed / open loop - the influence of counter modality}**

To estimate fluctuations in response, we inspected the temporal detection rather than the overall performance.

We estimated the momentary DP for each modality, as described in the technical details section \ref{subsubsec:DPcalc}.

Figure~\ref{fig:ResponseFluctuationsExample} shows an example of one subject response fluctuations in all four sessions.

\begin{figure}[H]

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**\includegraphics**[scale=0.5,trim={3cm 1cm 4.8cm 0 },clip]{./graphics/Fluctuations/DPavcorr\_ExMix\_DR\_M\_32forPresentation.png}}

\caption[\textbf{Example of response fluctuations in all sessions}]{\textbf{Example of response fluctuations in all sessions} the four panels show filtered responses of all sessions of one subject.

Red represents responses for visual stimuli, while blue represents auditory stimuli.

Fluctuation levels are expressed as the standard deviation of the filtered response.

**\label{fig:ResponseFluctuationsExample}**}

\end{figure}

It was expected, and indeed found, that a modality that was in CL displayed less fluctuation than when was in an OL, since the CL was *clamping it* to do exactly this.

**\paragraph**{}

Figure ~\ref{fig:Influence\_on\_STD} summarizes the fluctuation levels of all subjects.

For the inspection of the interactions \textit{between} the modalities, we checked the influence of the second modality being in OL/CL on the fluctuations of the first when itself was in \textit{open loop}.

The results show that influence indeed exists but only in one direction. When auditory was in OL, the visual fluctuations decreased relative to the case where both modalities were in OL, as seen in~\ref{subfig:Influence\_on\_STD\_V}.

However, such influence was not found in auditory OL where fluctuations have not changed whenever the visual modality was in either regime, as shown in ~\ref{subfig:Influence\_on\_STD\_A}.

The meaning is that we found an asymmetry between the modalities: only the fluctuations of the visual response were effected by auditory relations with response (CL or OL), while auditory was not influenced by visual relations with response.

When either modality was in CL, the effect of the controller of suppressing the fluctuation was dominant, and no interaction was found between the modalities.

\begin{figure}[H]

\raggedleft{

\subfloat[Visual]

{**\includegraphics**[scale=0.55, trim={0.1cm 0cm 0.5cm 0.8cm },clip]{./graphics/Fluctuations/CL\_RE\_Influence\_on\_STD\_V2.png}

**\label{subfig:Influence\_on\_STD\_V}**}

\subfloat[Auditory]

{**\includegraphics**[scale=0.55, trim={0.1cm 0cm 0.5cm 0.8cm},clip]{./graphics/Fluctuations/CL\_RE\_Influence\_on\_STD\_A2.png}

**\label{subfig:Influence\_on\_STD\_A}**}}

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\subfloat[Visual - influence of auditory CL/RE]

{**\includegraphics**[scale=0.55, trim={0.1cm 0cm 0.5cm 0.3cm },clip]{./graphics/Fluctuations/delatCL\_RE\_Influence\_on\_STD\_V.png}

**\label{subfig:delatCL\_RE\_Influence\_on\_STD\_V}**}

\subfloat[Auditory - influence of visual CL/RE]

{**\includegraphics**[scale=0.55, trim={0.1cm 0cm 1cm 0.3cm },clip]{./graphics/Fluctuations/delatCL\_RE\_Influence\_on\_STD\_A.png}

**\label{subfig:delatCL\_RE\_Influence\_on\_STD\_A}**}}

\caption[\textbf{Fluctuations of response}] {\textbf{Fluctuations of response} in the different experimental conditions:\newline

~\protect\subref{subfig:Influence\_on\_STD\_V}$\&$\protect\subref{subfig:Influence\_on\_STD\_A}: Pairs of STD levels of the DP traces of visual (Red) and auditory (Blue) responses in the different experiment conditions.

Dots represents individual subjects, and the lines that connect every pair of dots show the individual trends.

Error-bars mark the standard deviation (1$\sigma$) around the mean fluctuation levels of all subjects, and the median is marked with a white circle.

\newline On the left side of both panels, STD levels of either modality when in CL are low, and they are not affected by the regime of the other modality.

~\protect\subref{subfig:Influence\_on\_STD\_V} On the right side, visual DP fluctuations are decreased when auditory alone was in a CL relative to the session when both modalities were in OL.

~\protect\subref{subfig:Influence\_on\_STD\_A} On the right side, auditory fluctuations in OL do not change whenever visual modality is in either regime.

\newline~\protect\subref{subfig:delatCL\_RE\_Influence\_on\_STD\_V}$\&$\protect\subref{subfig:delatCL\_RE\_Influence\_on\_STD\_A}: Since fluctuation levels are highly diverse between subjects, we studied the individual differences ($\Delta STD$).

On average, in OL sessions, $\Delta STDs$ of the visual responses are lower than zero.

This reflects a per-subject influence of auditory fluctuations on the visual fluctuations.

Statistical significance with respect to the null hypothesis was found using t-test, and the p-value was 0.03.**\label{fig:Influence\_on\_STD}**}

\end{figure}

**\subsection{Temporal relationship between responses to auditory and of visual stimuli}**

Another way of inspecting the temporal relations between modalities is directly looking at the dynamic relations between their two response traces.

The traces of the two modalities were calculated while aligned to their actual times.

The filtered responses were then extrapolated to be evaluated also at times of stimulation of the other modality.

These aligned and extrapolated traces enabled calculating a temporal cross-correlation between them.

For the same process, extrapolations and cross-correlation were applied on the two vectors of input levels.

\newline We calculated a normalized cross-correlation for each pair of signals by the following formula:

\begin{align}\**label{eq:Xcorr}**

Xcorr(A,B)=\frac{1}{N-1} \sum\_{i=1}^{N} (\frac{A\_i - \sigma\_A}{\mu \_A})(\frac{B\_i - \sigma\_B}{\mu \_B})

\end{align}

Where $N$ is the signal length and $\sigma$ and $mu$ are the mean and standard deviation of the signals, respectively.

This revealed complex temporal relations between the modalities, as seen in figure~\ref{fig:AudioVisualXcorrInandDP}.

\begin{figure}[H]

\centering{

{**\includegraphics**[scale=0.6]{./graphics/AVresults/AudioVisualXcorrInandDP.png}}}

\caption[\textbf{Auditory-Visual X-correlation of Inputs and DP}]{\textbf{Auditory-Visual X-correlation of Inputs and DP}

\newline The output responses have a \textit{positive} correlation between them when both modalities are in CL (green on the left), while a \textit{negative} correlation is found when both are in the replay (OL) session (green on the right).

There is zero correlation between input levels in both cases (purple, both sides)

\newline Statistical significance was calculated using the t-test for X-correlation levels against the null hypothesis; asterisks mark significance and p-values are noted.

**\label{fig:AudioVisualXcorrInandDP}**}

\end{figure}

Any audio-visual correlation (both directions) cannot be attributed to any property of the input, because the auditory and the visual inputs have zero correlation between them.

Moreover, the difference between the correlation direction in OL and CL occurred despite the (almost) identical inputs which were delivered in these two sessions.

A \textit{Negative} correlation was found between the responses of the modalities when they were both in OL session.%, while there was no correlation between the inputs.

(A representative example of the counter correlations in OL is shown between the traces of the subject in figure~\ref{fig:ResponseFluctuationsExample}, top on the right).

This can account for the temporal and voluntary \textbf{shifts of attention} between the modalities.

CL paradigm prevented these shifts, as we showed that the correlation between responses in OL was \textit{Positive} for the same inputs (an example for the small positive correlations between DP traces in CL is shown in figure~\ref{fig:ResponseFluctuationsExample}, top on the left).

Although each modality had an independent controller, the process of relating to the response entrained fluctuations of the two modalities to each other, so they became correlated.

The way it occurred could be as follows: if the subject was focused during some period on the visual stimuli while neglecting the attention to the auditory ones, then the controller would have strengthened the next auditory stimuli to the extent it became inevitable not to detect.

The result, in this case, was concomitant alertness to both sources of stimuli.

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**\subsection{Audio and vision responses in the combined experiment have no recency effects}**

A known tendency in perception is the recency effect, which means that subjects tend to repeat last response more than justified by the input structure (the effect was demonstrated in the visual detection process in section ~\ref{subsec:POA}).

Hereby, this effect is evaluated in the bi-modal case. %, The options were as follows: Is it valid per-modality? or, per-combined responses? or, not at all?

%POA is a measure representing the relative portion of reversals in binary data as defined in \ref{eq:POA}.

In the current experiment, the stream of results was mixed, i.e. composed of responses to auditory and visual stimuli.

There were two ways to inspect the recency effect:

\begin{enumerate}

\item{}Is there recency within the results of each independent modality, although in half the cases stimuli were not actually consecutive?

\item{}Does this effect exist for the general responses of combined input sources?

\end{enumerate}

The measure that we used for evaluation of the effect is probability of alternation (POA), which is defined in equation \ref{eq:POA} in chapter \ref{subsec:POA}.

**\subsubsection{No recency effect within each modality}**

**\label{subsubsec:NoRecencyWithinMod}**

To test the first question, responses were separated into two vectors, auditory responses and visual responses, and POA of each of them was calculated separately.

The inputs of each modality were generated by the CL controller which resulted in an individual temporally-correlated input levels for each modality.

Since a structure of the input dictates the level of reference for probability of alternations (i.e. the POA which is expected without recency and other biases), we had to consider the actual structures that were delivered.

We used an instantaneous model to evaluate this expected value as follows:

The model reflected the static \& memory-less properties of the input-output relations for either modality (elaborated description of this model is found in the previous chapter~\ref{subsec:POA} and in figure ~\ref{fig:InstantenousModel}).

The parameters that were used in the model were the average values (across all subjects) of slope and threshold for either modality.

These values were obtained for each subject by generating psychometric curves for both auditory and visual responses and then extracting the slope and threshold of each curve by fitting it to a sigmoid, as described in~\ref{subsec:Psychometric\_curve}).

To be most precise, the inputs that were fed to the model were the actual inputs which were presented to the subjects in the OL session (a replay of the inputs recorded in the CL procedure).

**\paragraph**{}

In the case of CL, it was expected to find high alternation rates since each controller prevented long streaks \textit{in its modality}.

Indeed, in figure \ref{fig:AV\_VotePOAPerModality\_Comp2Modle}, these high alternations rates appear wherever either modality is in CL regardless of the regime of operation of the other modality.

However, in OL, we found that responses to each modality \textit{did not have the tendency to recency}.

For example, the visual series of responses to OL stimuli were the same as the instantaneous model under auditory OL (left panel, VRE\\_ARE) and under auditory CL (left panel, VRE\\_ACL).

In comparison to the results of the experiment in visual modality alone \ref{subsec:POA},

this implies that analyzing the visual trials alone in a series of mixed visual-auditory trials, the recency effect disappeared regardless of the manipulation applied on the other modality.

\begin{figure}[H]

\centering{

{**\includegraphics**[scale=0.6, trim={1.5cm 0 0 0},clip]{./graphics/AVresults/AV\_VotePOAPerModality\_Comp2Modle.png}}}

\caption[\textbf{Probability of alternation in responses per modality}]{\textbf{Probability of alternation in responses per modality}

On the left, POA of visual responses.

Red area represents STD between subjects around the mean, thin lines stands for 95\% confidence level, and the white circle stands for the median.

POA obtained from an instantaneous model applied to the input stimulus is marked by a horizontal dotted line.

On the right, in blue, POA of auditory responses.

Asterisks mark the significance for POA being different than the value dictated by the input structure (P-value for t-test is notated).

**\label{fig:AV\_VotePOAPerModality\_Comp2Modle}**}

\end{figure}

This finding, that no recency effect existed within each modality, could have been a result of the interrupts of the other modality in the sequence of responses, which dismissed the effect for the overall signal.

To test this hypothesis, we checked if some recency existed specifically for the trails were the modality of the previous stimulus was the same as of the current one (on average, these are half of all the trials of each modality).

The alternation rate of only consecutive trials of the same modality was calculated, and surprisingly, the result did not change in this case and within either modality there was no recency effect at all, as shown in figure~\ref{fig:AV\_VotePOAPerModStay}.

This result is opposite to the result we have found in the experiment of \textit{visual modality alone}. There we have shown that recency of responses exists beyond the inputs demand for all input structures.

The difference in results highlights once again how specific context and experiment conditions, such as raising the cognitive load by admixing modalities, can alter results and even modify basic properties of detection.

\begin{figure}[H]

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{**\includegraphics**[scale=0.6, trim={1.5cm 0 0 0},clip]{./graphics/AVresults/AV\_VotePOAPerModalityStay\_Comp2Modle.png}}}

\caption[\textbf{Probability of response alternation per modality for consecutive trials of the same modality}]{\textbf{Probability of response alternation per modality for consecutive trials of the same modality}

\newline These cases are on average half of all the trails of each modality (67-72 trials per subject per session, dependent on the number of sham trials in the experiment).

\newline Marking as in figure~\ref{fig:AV\_VotePOAPerModality\_Comp2Modle}.

**\label{fig:AV\_VotePOAPerModStay}**}

\end{figure}

**\subsubsection{No recency effect between the modalities}**

For inspection of the second question - recency in the combined response, there was no need to separate the results vector, so POA of responses was calculated for it as a whole.

For calculating the reference POA which is derived from the input structure, we merged the instantaneous model outputs, which were generated for the previous analysis in~\ref{subsubsec:NoRecencyWithinMod}, thus keeping the original order of presentation.

The response alternation rate was calculated upon this combined output and compared to the reference value.

Figure~\ref{fig:POA\_All} shows that also between the modalities there was no recency of responses beyond what is dictated by the input structure.

\begin{figure}[H]

\centering{

{**\includegraphics**[scale=0.6]{./graphics/AVresults/AV\_VotePOAComb\_Rel2Modle.png}

\caption[\textbf{Probability of alternation of all responses}]{\textbf{Probability of alternation of all responses}

The POA overall stream of responses in OL is not lower than the alternation rate, which is expected from the input structure (marked with a horizontal line).

There is no recency effect of inter-modality responses.

**\label{fig:POA\_All}**}}}

\end{figure}

Altogether, we found that recency effect was not found in any way in this combined auditory-visual paradigm.