1pPPb

Ventriloquism effect and aftereffect in the distance dimension

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Background

Visual (V) signals can influence the perceived location of **auditory** (A) stimuli. This interaction has been extensively studied in horizontal dimension:

Ventriloquism effect (VE) - perceived origin of a sound is shifted towards (or "captured by") the location of concurrently presented V stimulus when the stimuli are at separate locations (Jack and Thurlow, 1973).

Ventriloquism aftereffect (VA) - shifts in perceived A location persist after repeated presentation of horizontally mismatched A-V stimuli, even after V is removed (Recanzone, 1998). This demonstrates rapid short-term recalibration of auditory localization (Shams et al., 2011).

In distance dimension only a few previous studies available. Most of them suggest that VE is stronger when A stimuli are associated with closer (vs. further) V stimuli:

Proximity image effect - in anechoic space, A object is unified with a closer V target (Gardner, 1968).

A-V unification in VE is more effective for closer V stimuli (Mershon, 1980; Zahorik, 2003), but experiments were performed only with a single fixed V stimulus.

Closer V stimuli tend to induce stronger VA than further V stimuli (Min, Mershon 2005).

Short-term A-V re-calibration can be linear or logarithmic (in horizontal dimension studied by Shinn-Cunningham et al., 2005).

Current study

Systematically study VE and VA in distance dimension for a range of target distances directly ahead of listener.

Induce VE and VA using multiple speaker (A) + LED (V) pairs with a fixed A-V distance ratio, by placing V 30% further or closer than A.

Questions:

Is the strength of induced VA & VE:
- constant across the examined range?
- equal in V-Further and V-Closer conditions (see Fig. 1)?

Is there a direct relationship between observed VA and VE patterns?

Does the mechanism of A-V alignment operate on linear or logarithmic scale?

Hypotheses:

H1: The stimuli will induce VE in distance dimension. It will be stronger in the V-Closer than V-Further condition (similar to Mershon et al., 1980, or Zahorik, 2003).

H2: The induced shifts will persist to interleaved A-only stimuli, creating VA. The VA strength will be proportional to VE, as in Kopco et al. (2009). VA will be stronger for V-Closer adaptors (as in Min and Mershon, 2005).

Methods

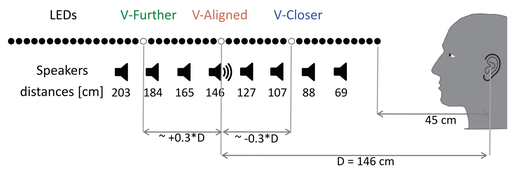


FIGURE 1 Experimental setup and stimuli. Circles represent LEDs (open = LED on, filled = LED off). In the AV presentations, only one LED and one speaker was on at any given time. The LED was aligned with the speaker in AV-Aligned condition. In the V-Closer and V-Further conditions, the LED was approximately 30% closer or further, respectively, than the active speaker.

Setup (Fig. 1):

9 speakers covered by sound-transparent cloth in front of the subject at the ear level (closest speaker not used).

Custom made array of LED lights mounted 20 cm above the speaker array.

Stimuli presented via TDT RX8 and Crown CTs 8200 amplifier.

Stimuli:

A-only stimuli - 300 ms broadband noise presented at fixed level; received level range 49-54 dB(A).

AV stimuli - A component identical to A-only; V component (LED light) turned on and off in synchrony with A.

Conditions (Fig. 1):

V-Aligned - LED at the same distance as sound.

V-Closer - LED 30% closer than sound.

V-Further - LED 30% further than sound.

Task:

Subjects indicated perceived sound distance by selecting the closest LED using a trackball.

Subjects instructed to ignore visual stimuli and focus on the perceived sound distance.

Experiment (Fig. 4a):

34 subjects.

2 one-hour sessions, condition (V-Closer vs. V-Further) fixed within session.

Each session contained 11 runs (Fig. 4a).

64 trials per run (self-paced), 500 ms inter-trial pause.

Two types of run:
- AV runs - 75% of AV trials randomly interleaved with A-only (probe) trials (25%);
- A-only runs - all A-only trials

Room:

Sound-attenuated small (2.3 m x 3.3 m) reverberant room. Background noise 35 dB(A).

Results - Ventriloquism effect and aftereffect

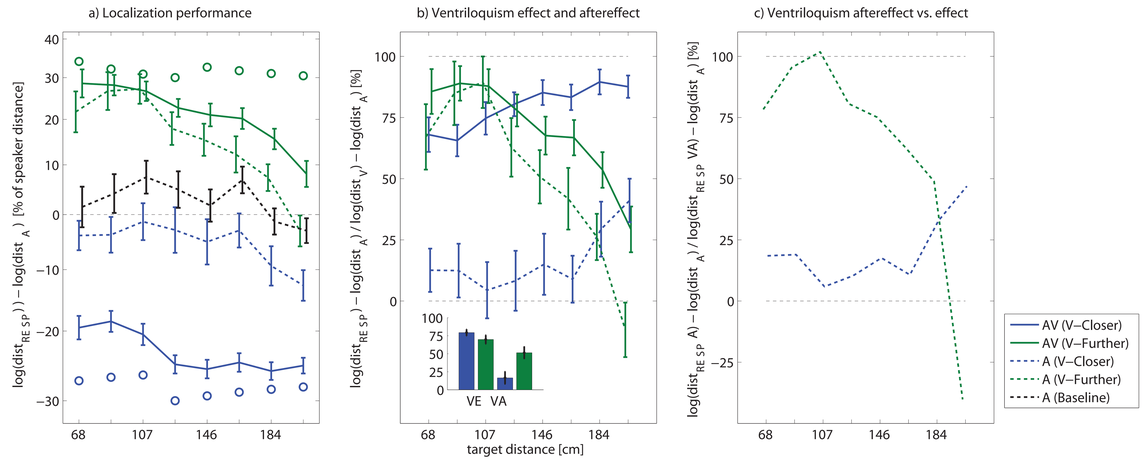


FIGURE 2 (a) Mean localization responses during adaptation runs (average of runs 4-8) and A-only baseline runs (average of runs 2,3) as a function of target distance, plotted on a log scale and expressed in percent of target distance. Circles denote the location of misaligned LEDs (V component of incongruent AV stimulus). Solid blue and green lines represent responses on AV trials. Dashed blue and green lines represent responses on A-only trials in adaptation runs (interleaved with AV trials). The V-Closer data are shown in blue; V-Further data in green. Black dashed line represents baseline from A-only runs. (b) Ventriloquism effect (solid) and aftereffect (dashed line) expressed as a proportion of the size of the displacement of V component relative to A component in misaligned AV stimuli. Data plotted as a function of target distance. Thin dashed lines represent minimum and maximum of the effect. In panel bars: Size of VE (left-most two bars) and VA (right-most two bars) averaged across target distance. (c) VA as a portion of VE as a function of target distance. Data from two subject groups are pooled together. All figures show across-subject means and SEMs; panel (c) has no error bars.

Figure 2a shows raw responses in adaptation and baseline conditions relative to (re.) actual A-component of target. Shifts are observed for both V-Closer and V-Further conditions and both A-only and AV trials (colored lines). Size of shifts varies with condition, stimulus type and target distance. In baseline, bias very small (black line).

VE and VA are plotted as a function of source distance in Fig. 2b. VE (solid lines) was strongest (90%) for far sources in V-Closer condition and for near sources in V-Further condition. The effect decreased in both conditions for targets at opposite end of range (30% V-Further, 65% V-Closer). VA (dashed lines) was weaker but roughly proportional to VE (compare corresponding dashed and solid lines).

The proportion of VA relative to corresponding VE is shown in Fig. 3c. VE generalized to VA much more in V-Further than V-Closer condition. On average, VA was 60% of VE in V-Further and 25% of VE in V-Closer condition.

Results - Persistent and immediate VA

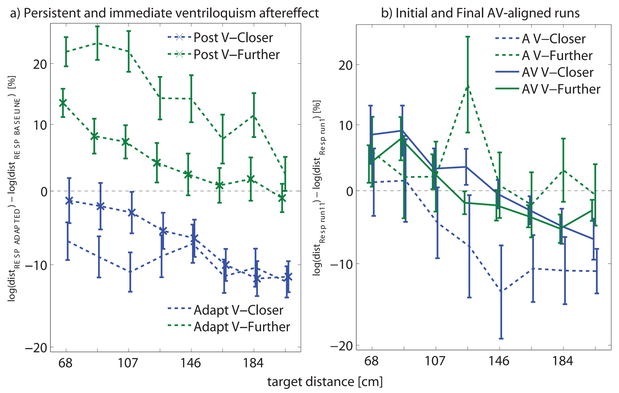


Figure 3 (a) Immediate and persistent VA relative to pre-adaptation baseline (A-only runs 2 & 3). Dashed lines without symbols - shift in A-only responses during adaptation (runs 4-8). Dashed lines with 'x' - shift in A-only responses the post-adaptation (runs 9-10). (b) Performance in the final (run #11) vs. initial (run #1) AV-Aligned runs. Solid lines - AV trials (75%). Dashed lines - A-only trials (25%).

Both ventriloquism effect (VE) and ventriloquism aftereffect (VA) vary with distance and direction of induced shift.

VE is stronger in V-Closer condition, but VA unexpectedly stronger in V-Further condition.

The short-term adaptation persists for minutes and tens of minutes after adaptation, with equal magnitudes in V-Closer and V-Further conditions.

Persistence of VA was evaluated by comparing performance in post-adaptation runs 9 & 10. The shift induced by the displaced V signals persisted even after the adaptation runs (dashed lines with 'x' symbols in Fig. 3a). Similar to **immediate VA** observed during adaptation runs (dashed lines without symbols). V-Further stimuli caused a shift away from the listener for nearby targets, V-Closer stimuli caused a shift towards the listener for distant targets. Magnitudes of shifts were similar for V-Closer and V-Further conditions, even though the immediate VA shifts were larger for V-Further.

Figure 3b shows the change in performance between the initial and final runs (both V-Aligned) of each session. The AV responses are unaffected by the adaptation runs (solid lines lie on top of each other). A-only responses still show bias (dotted lines), even though they are interleaved with V-Aligned stimuli and even though no adaptation stimuli were presented in preceding 2 runs. The A-only bias is mostly in the V-Closer data (blue dashed line).

Discussion

Summary:

This study examined Ventriloquism Effect (VE) and Aftereffect (VA) induced by AV stimuli over a range of distances using a constant V-to-A distance ratio. Visual stimuli presented simultaneously with auditory targets shifted perceived location of the auditory targets in distance dimension (Ventriloquism Effect). The resulting shift had complex pattern, varying between 35 and 90% of AV displacement. The effects were more complex compared with previous results which used only one V component (Gardner, 1968; Mershon et al.,1980; Zahorik, 2003).

Hypotheses evaluation:

H1: As expected, V-Closer exhibited stronger VE than V-Further but only for targets at distances larger than 1.5m, for closer distances the V-Closer effect was smaller or equal to V-Further.

H2: Unexpectedly, VA was stronger in V-Further than V-Closer condition. However, this difference was not confirmed when persistent VA was evaluated.

Discussion:

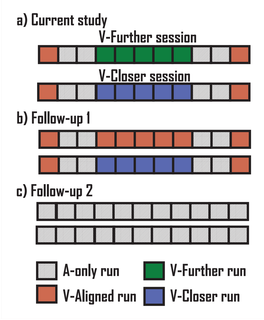
VE & VA was stronger for nearby targets in V-Further condition, and for distant targets in V-Closer condition. This could be a result of:
- effect of target plausibility. If the shifted response falls into the actual A-range, then the effect is stronger than when the response falls outside the A-range (known from initial runs).
- "cumulative" adaptation. If V-Further AV discrepancy at certain location affects all closer locations, in addition to the target location, then the effect is expected to decrease with target distance (and vice versa for V-Closer AV discrepancy). In other words, adaptation appears to generalize mostly to locations that are in the direction opposite that of the induced shift.
- underlying neural representation not using log space as assumed here. For V-Further, the pattern is consistent with adaptation in linear space (i.e., a constant shift). However, V-Closer adaptation shows pattern opposite to what linear shift would predict. Other types of representation need to be examined.

VA and VE could be affected by baseline performance. If referenced to the pre-adaptation A-only baseline, VA difference between V-Closer and V-Further becomes smaller, however V-Further is still stronger for near targets (Fig. 3a).

The relative strength of the V-Closer vs. V-Further effects varied. V-Closer was stronger for VE (Fig. 2b), weaker for immediate VA (Fig. 2c), equal to V-Further in post-adaptation VA (Fig. 3a), and stronger when initial vs. final runs were compared (Fig. 3b). This suggests that multiple adaptation mechanisms might operate at different time scales.

Results also might be affected by design choices and technical limitations:
- the 30% AV disparity for V-Closer vs. V-Further conditions means that a stronger disparity was induced in V-Closer condition on a log scale;
- the distribution of V components with respect to A components in AV stimuli was slightly non-uniform (see circles in Fig. 2a);
- speaker and LED distribution was linearly uniform, i.e., denser for far targets if underlying representation is logarithmic;
- the same LEDs were used to induce the shift and to collect responses. Therefore, an association between individual LEDs and sound distances could have been induced, instead of shifts in auditory maps.

Follow-up studies



Currently, two follow-ups:
1. What is the baseline performance with AV information (Fig. 4b)?
2. How does performance change if no V information is provided (Fig. 4c)?

Future Questions:

What is the distance AV alignment mechanism?

How does initial AV/A exposure affect performance?

What is the effect of magnitude of AV-discrepancy?

How do stimulus characteristics (duration, AV synchrony, intensity, envelope/number of onsets, or ecological validity) affect VA & VE?

FIGURE 4 (a) Organization of the current experiment. Each subject performed two sessions (V-Closer session followed by V-Further session, or vice versa). Each session started by AV-Aligned run, followed by two A-only runs, 5 incongruent AV runs, two A-only runs, and a final AV-aligned run. (b) Experiment to determine V-Aligned baseline. (c) Experiment to determine A-only baseline.

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