Influence of cross-modal cues on heading perception

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Abstract

Heading perception is established using visual and inertial cues, but the relative influence of these cues on each other is uncertain. In other bi-modal experiments, there is an integration of the two stimuli at close offsets (e.g. "Ventriloquist Effect"), but a decrease in influence at larger offsets such that subjects are likely to respond differently in both modalities. We hypothesized that visual-inertial integration would follow a similar trend. This study examined visual and inertial heading perception in the horizontal plane in human subjects presented with concurrent visual and inertial stimuli. The subjects were asked to report one of the stimulus' direction. As the experiments were performed, the results led us to perform subsequent experiments. In total, the subjects performed 4 different experiments (in order):

Experiment 1 Hypothesis: visual stimuli would not affect inertial perception at greater than 40°.

Experiment 2 Hypothesis: visual stimuli would have no effect on inertial perception at 90°.

Experiment 3 Hypothesis: visual influence would not affect inertial perception if they were presented at opposite directions of each other.

Experiment 4 Hypothesis: the different method of reporting visual stimuli affected the results of Experiment 3.

The results for each experiment at reflective offset angles (e.g. -60° and 60°) were combined. Visual influence on inertial perception was found at small (<60°) and large (>90°) offsets. Visual influence was not found when subjects reported on relative offsets around 180° (+/- 60°) with small inertial ranges (-30° to 30°). Visual influence was found when subjects reported on relative offsets of -150° to 150° with large inertial ranges (-140° to 140°).

Introduction

Some common vestibular motion disorders are thought to be caused by a mismatch of visual and vestibular signals. Vestibular perception research has been largely focused on perceptual thresholds in unimodal conditions. Current work that focused on visual-vestibular integration has developed models that demonstrated an optimal Bayesian integration when visual and vestibular heading angles were offset (inertial heading angle different than visual heading angle). However, the optimal integration breaks down with larger visual-vestibular heading offsets. Understanding the integration of visual and vestibular stimuli in non-optimal conditions will provide insights to treat vestibular disorders and hastened adaptation of patients with vestibular lesions.

Methods

Subjects

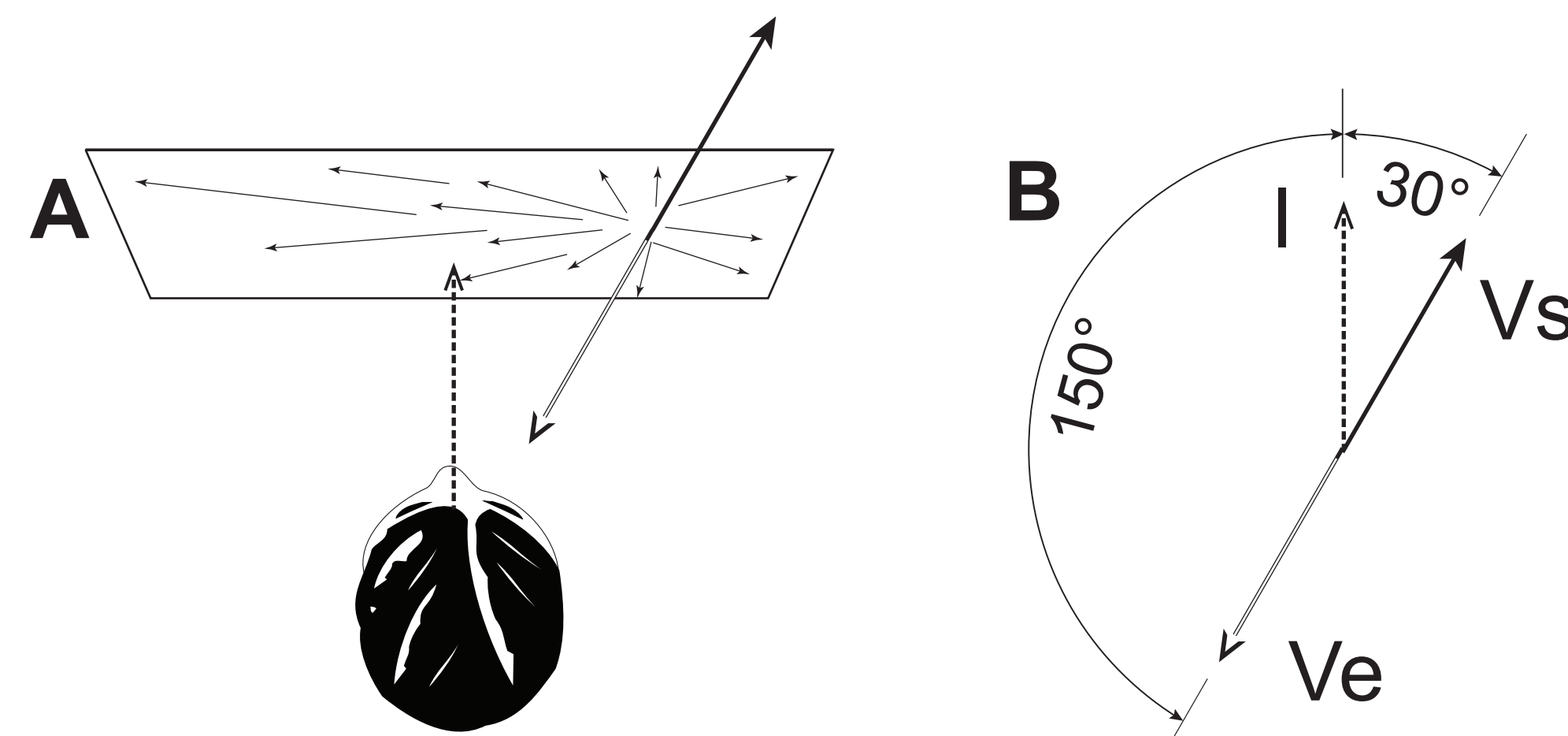Five human subjects (3 female) ages 25 to 69 were enrolled.

Experimental setup

Stimuli included both a visual and inertial component which are offset from each other. In this example the subject is being moved forward while the visual stimulus is consistent with moving through a fixed environment at a heading shifted 30° to the right.

Subjects were asked to provide one of 3 possible directions:

1) The direction of inertial motion (I, dashed arrow).

2) The direction of self-motion implied by the visual stimulus (Vs, solid arrow) which can also be described as the direction the stars were coming from.

3) The direction of environmental motion implied by the visual stimulus (Ve, hollow arrow) which can also be described as the direction the stars are going.

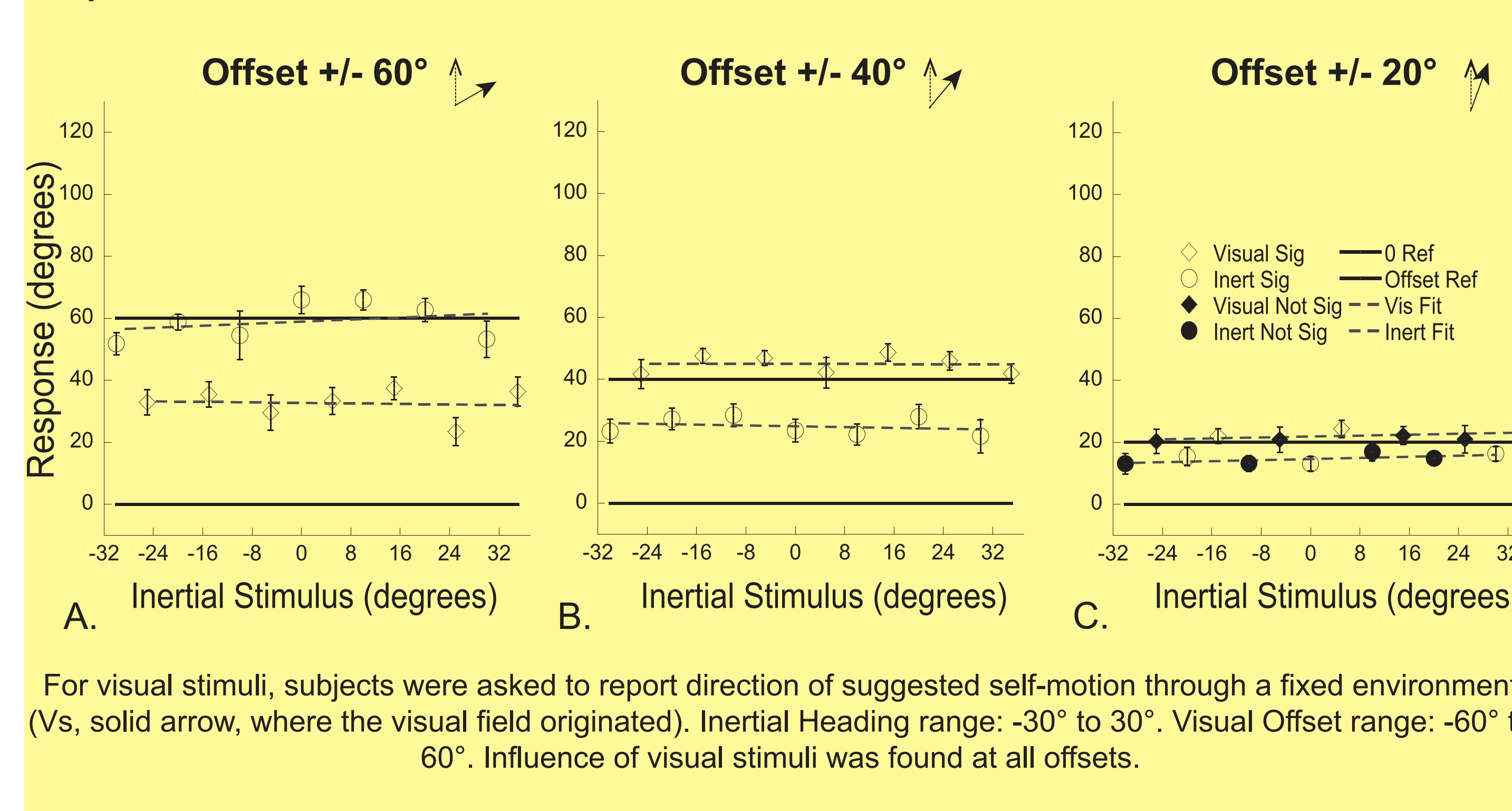*Note*: Vs and Ve will always be in opposite directions.

Note: Range of motion for inertial and visual headings is described below their respective figures.

Analysis

The actual inertial heading is subtracted from both the visual and inertial perceived headings, leaving an offset value for the visual heading and an error value for the inertial heading. The experiment began with an exploration of influence of visual stimulus on inertial perception, so a paired two-tailed t-test was run between the visual and inertial responses at each matching angle (p<0.05). For the coordinate system in use (0±180°), the responses were transformed to be within 180° of the offset amount (i.e. if the visual stimuli was -200°, the raw response value would be 160°). Both the positive and negative visual offsets were combined by reflecting the responses of the negative offsets. To obtain the level of influence per subject, the visual response was subtracted from the inertial response and divided by the total offset and then multiplied by 100 to get the percent of visual influence on inertial response.
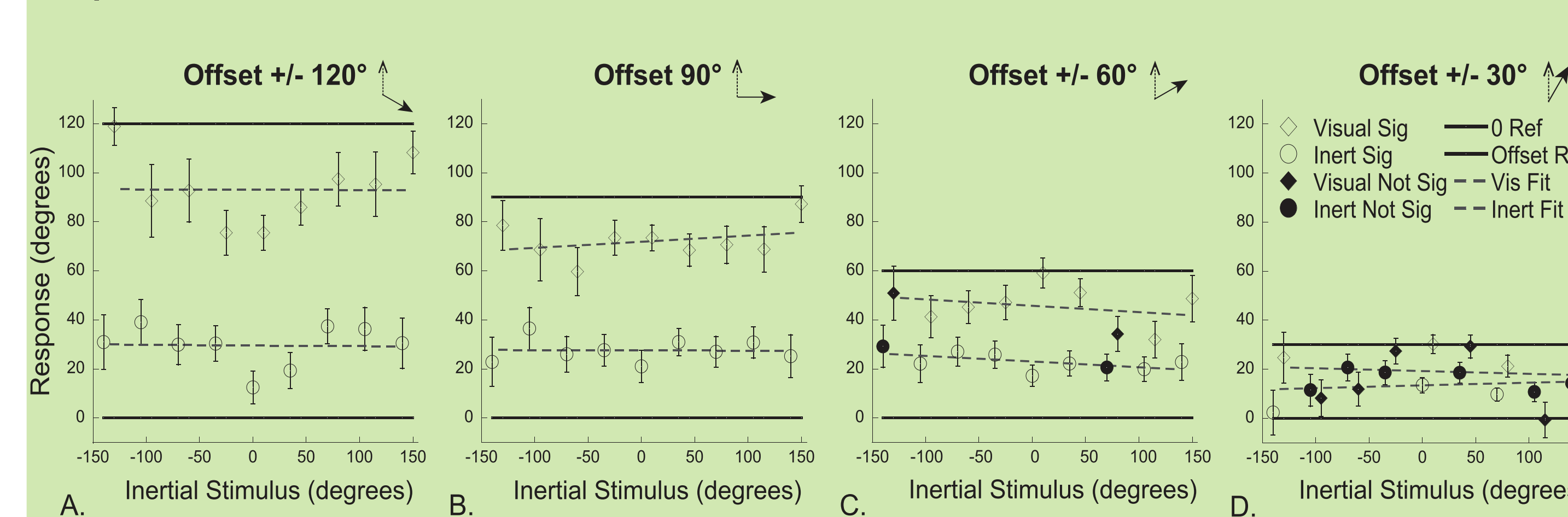
Results

Experiment 1

For visual stimuli, subjects were asked to report direction of suggested self-motion through a fixed environment (Vs, solid arrow, where the visual field originated). Inertial Heading range: -30° to 30°. Visual Offset range: -60° to 60°. Influence of visual stimuli was found at all offsets.

Experiment 2

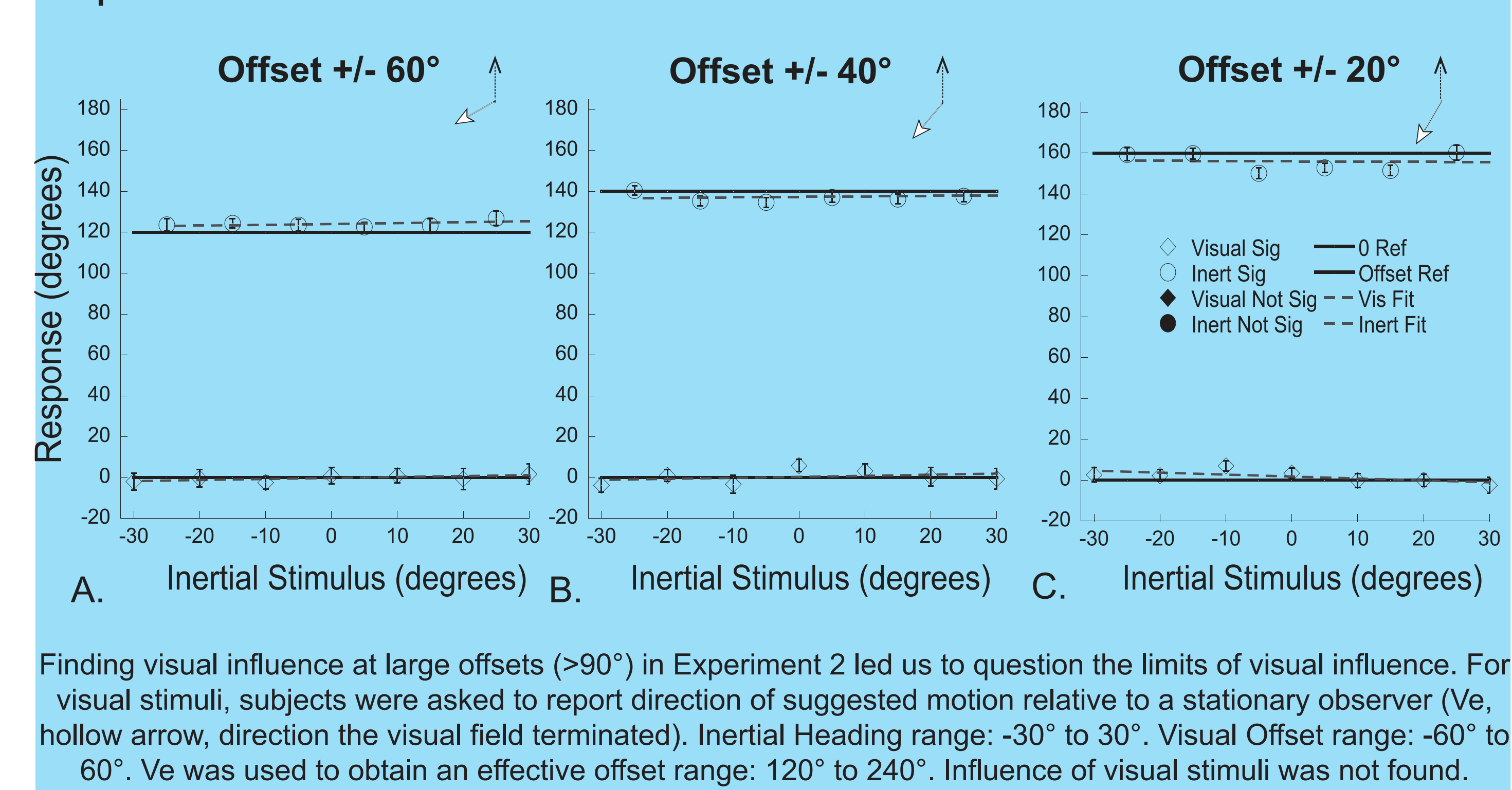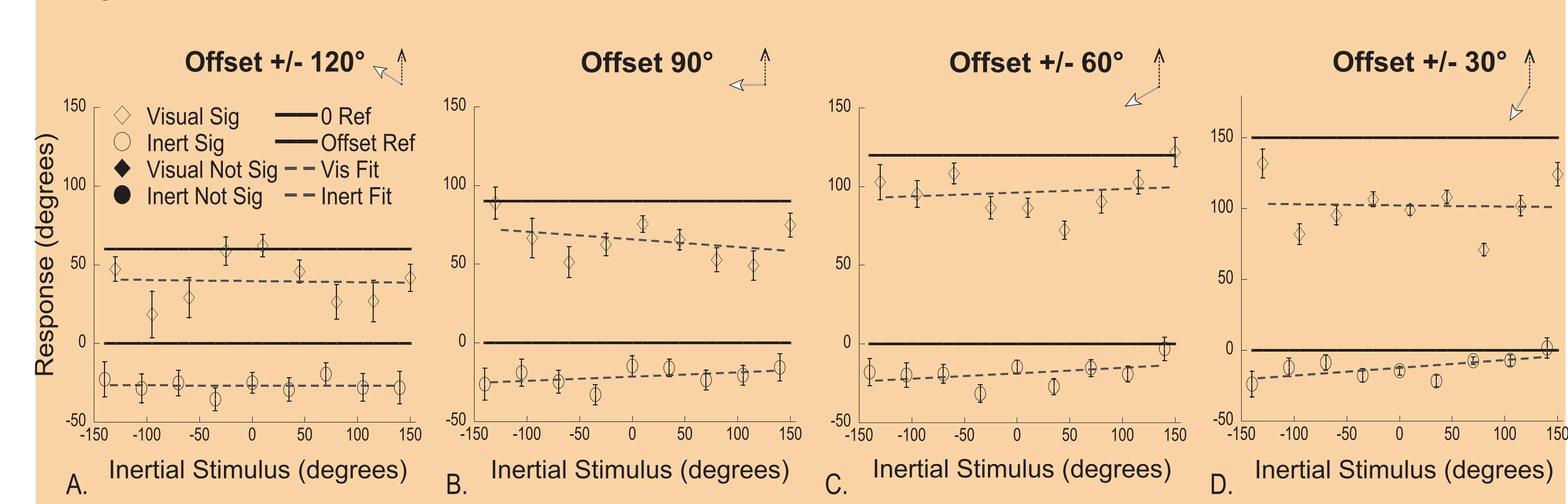Finding visual influence at large offsets (>40°) in Experiment 1 led us to expand the range of motion for visual and inertial stimuli to obtain larger offsets. For visual stimuli, subjects were asked to report direction of suggested self-motion through a fixed environment (Vs, solid arrow, where the visual field originated). Inertial Heading range: -140° to 140°. Visual Offset range: -120° to 120°. Influence of visual stimuli was found at all offsets.
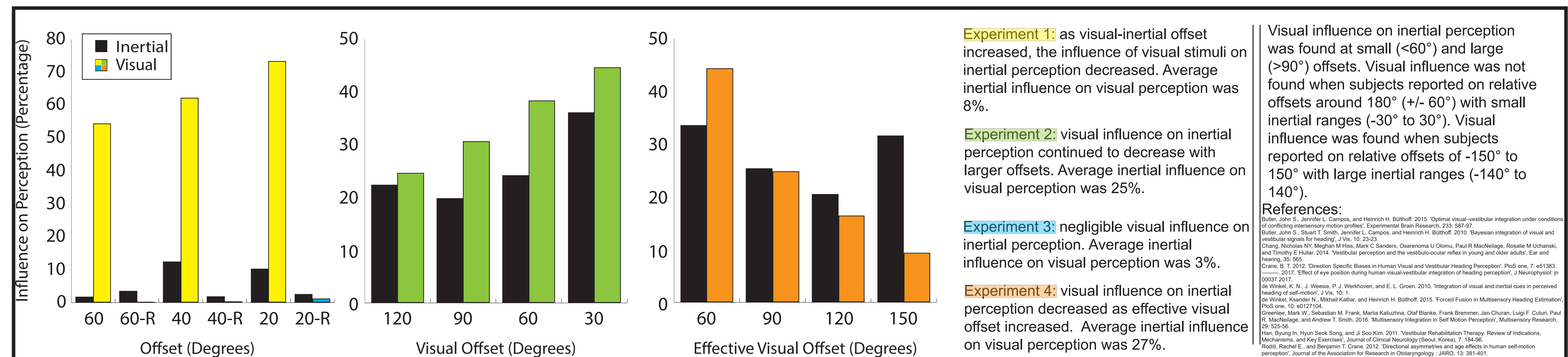
Experiment 3

Finding visual influence at large offsets (>90°) in Experiment 2 led us to question the limits of visual influence. For visual stimuli, subjects were asked to report direction of suggested motion relative to a stationary observer (Ve, hollow arrow, direction the visual field terminated). Inertial Heading range: -30° to 30°. Visual Offset range: -60° to 60°. Ve was used to obtain an effective offset range: 120° to 240°. Influence of visual stimuli was not found.

Experiment 4

Was the lack of visual influence in Experiment 3 caused by asking for Ve? For visual stimuli, subjects were asked to report direction of suggested motion relative to a stationary observer (Ve, hollow arrow, direction the visual field terminated). Inertial Heading range: -140° to 140°. Visual Offset range: -120° to 120°. Ve was used to obtain an effective offset range: -150° to 150°. Influence of visual stimuli was found at all offsets, suggesting that the effect of experiment 3 was not due to asking for Ve.

Summary

Experiment 1: as visual-inertial offset increased, the influence of visual stimuli on inertial perception decreased. Average inertial influence on visual perception was 8%.

Experiment 2: visual influence on inertial perception continued to decrease with larger offsets. Average inertial influence on visual perception was 25%.

Experiment 3: negligible visual influence on inertial perception. Average inertial influence on visual perception was 3%.

Experiment 4: visual influence on inertial perception decreased as effective visual offset increased. Average inertial influence on visual perception was 27%.

Visual influence on inertial perception was found at small (<60°) and large (>90°) offsets. Visual influence was not found when subjects reported on relative offsets around 180° (+/- 60°) with small inertial ranges (-30° to 30°). Visual influence was found when subjects reported on relative offsets of -150° to 150° with large inertial ranges (-140° to 140°).

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