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Shifts in Audiovisual Processing in Healthy Aging

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Abstract

Purpose of Review—The integration of information across sensory modalities into unified percepts is a fundamental sensory process upon which a multitude of cognitive processes are based. We review the body of literature exploring aging-related changes in audiovisual integration published over the last five years. Specifically, we review the impact of changes in temporal processing, the influence of the effectiveness of sensory inputs, the role of working memory, and the newer studies of intra-individual variability during these processes.

Recent Findings—Work in the last five years on bottom-up influences of sensory perception has garnered significant attention. Temporal processing, a driving factors of multisensory integration, has now been shown to decouple with multisensory integration in aging, despite their co-decline with aging. The impact of stimulus effectiveness also changes with age, where older adults show maximal benefit from multisensory gain at high signal-to-noise ratios. Following sensory decline, high working memory capacities have now been shown to be somewhat of a protective factor against age-related declines in audiovisual speech perception, particularly in noise. Finally, newer research is emerging focusing on the general intra-individual variability observed with aging.

Summary—Overall, the studies of the past five years have replicated and expanded on previous work that highlights the role of bottom-up sensory changes with aging and their influence on audiovisual integration, as well as the top-down influence of working memory.

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Conflict of Interest

Sarah H. Baum and Ryan Stevenson declare that they have no conflicts of interest.

Human and Animal Rights and Informed Consent

This article does not contain any studies with human or animal subjects performed by any of the authors.

Keywords

Multisensory integration; Aging; Sensory processing; Speech perception; Temporal processing; Inverse effectiveness; Working memory; Variability

INTRODUCTION

It is well established that sensory processing goes through many changes with healthy aging, typically resulting in a gradual decline of both visual and auditory abilities. Less studied, however, is how the interactions between sensory modalities change with aging, specifically how sensory information is integrated across individual sensory modalities. Multisensory integration, in general, confers many perceptual and behavioural benefits, in general resulting in faster and more accurate perceptual representations of the external world [1-3]. A canonical exemplar of this finding – and one particularly relevant in aging populations – is the ability to perceive speech in noise. The combination of perceiving both the auditory and visual speech signals provides a perceptual boost above what a listener can glean from each sensory modality in isolation, and often beyond what would be predicted by mere statistical facilitation resulting from the availability of multiple pieces of information.

How the behavioural and perceptual benefits associated with multisensory integration change across the lifespan is an active field of research. Here, we will review and synthesize research on the topic of audiovisual integration in aging populations, with a particular focus on new findings relating to bottom-up changes in sensory processing including temporal processing and the impact of degraded sensory inputs, top-down changes impacting multisensory integration, including changes in working memory, and finally, variability within older adults in terms of multisensory integration.

Work in the field of multisensory integration over the last three decades has solidified three guiding principles that seem to underlie the perceptual benefits observed with multisensory integration [4]. The first two principles, the temporal and spatial principles, suggest that the more temporally synchronous [5-27] and spatially coincident [9, 14, 22, 28-35] two sensory inputs are, the more likely they are to be perceptually bound into a unified percept, and thus resulting in greater multisensory benefits. Given known decreases in temporal perception in aging in particular, the temporal aspect has been targeted in recent research. The third is the principle of inverse effectiveness, which suggests that the less effective the unisensory components of a stimulus pair are in driving a response, the more multisensory benefit will be incurred [6, 36-44, 1, 45-48]. This pattern of inverse effectiveness holds until the unisensory components of a multisensory input become highly unreliable, at which point models of optimal integration demonstrate a reduction in multisensory benefit [49-51]. In recent years, work has furthered our understanding of how these principles influence multisensory integration in aging.

The Influence of Temporal Processing

One of the first stages of audiovisual integration is determining which sensory inputs should be integrated and which should be processed independently. Perhaps the strongest cue that

two sensory inputs should be integrated is their temporal alignment – when two inputs are temporally coincident, they are more likely to have originated from a single external event and thus should be integrated [52]. The ability to make use of this cue, however, is dependent upon the fidelity of an individual's temporal perception [53]. With healthy aging, recent work has shown that the precision of temporal perception tends to decrease, though results have not been wholly consistent [54-60]. A series of recent studies have solidified this finding, and have expanded our knowledge of the role that changes in temporal processing have on changes in multisensory integration in older adults.

Many of these studies use tasks in which participants directly report their perception of stimulus timing while being presented with audiovisual stimulus pair in which the stimulus onset asynchronies are parametrically varied. These include simultaneity judgment tasks (SJ) in which a participant reports if two stimuli were synchronous or not and temporal order judgment tasks (TOJ) in which the participant report which stimulus came first [61, 62] (See Figure 1A). From a participant's reports, experimenters can then calculate a participant's *temporal binding window* (TBW), or the window of time within which a participant perceives two stimuli to be synchronous, and thus is likely to integrate them [20, 63-65].

For example, a recent study used a two-interval-forced-choice (2IFC) SJ task to compare the magnitude of the TBW in older and younger adults TBWs, as measured with simple pure tones and Gabor patches [59]. In the 2IFC version of an SJ task, participants are shown two audiovisual stimulus pairs, with one pair being synchronous and the other pair being asynchronous to varying degrees, and the participant must indicate which stimulus pair was synchronous. Older adults were shown to have larger TBWs, that is, they were less able to accurately determine which presentation was synchronous. This effect was seen regardless of whether visual or auditory stimuli were presented first, but was only seen with low frequency (4000 Hz) auditory stimuli. Furthermore, by presenting stimulus pairs for each subject at their individual detection thresholds, this study was able to provide greater evidence that older adults exhibit poorer temporal acuity even when unisensory declines are taken into account.

Another way to indirectly measure temporal acuity is with a set of tasks that utilize multisensory illusions where the illusory percept relies on the integration of the auditory and visual cues. These include illusions such as the McGurk Effect [66] (See Figure 1B), the sound-induced flash illusion [67] (See Figure 1C), and the stream-bounce illusion [68] (See Figure 1D). Within each of these illusions, experimenters can either measure the rate of illusory percept to determine how often a participant integrates audiovisual information, or experimenters can manipulate the timing of the auditory and visual components and extract a TBW. See Figure 1 for graphical description of each behavioural task.

In the sound-induced flash illusion, an individual is presented with a single visual flash paired with varying numbers of auditory beeps, and instructed to count the number of flashes while ignoring the beeps [67] (See Figure 1C). When the auditory and visual stimulus inputs are integrated, the presence of multiple beeps induces the perception of a second (or third) illusory flash. Given that multiple beeps cannot be presented simultaneously, this task includes an inherent temporal asynchrony, and studies of younger

adults have shown that larger TBWs are associated with an increased perception of this illusion [53]. Recent work has shown that older adults are more susceptible to the sound-induced flash illusion [69]. A second study utilizing this illusion kept the single flash and one beep simultaneous while parametrically varying the presentation of the second beep, ranging from preceding the beep/flash pair by 270 ms to lagging by 270 ms in 40 ms steps. Older adults were more likely to perceive illusory flashes than younger adults, particularly at temporal offsets over 100 ms [56]. Additionally, this study also showed another “real-world” effect of reduced multisensory processing in aging as larger TBWs were associated with increased levels of falls in older adults.

The previously described studies report on the most commonly measured effect associated with the sound-induced flash illusion, a “fission” effect in which a single flash is perceived as two or more flashes. The inverse effect can also be measured, a “fusion” effect, where two flashes are presented with a single beep, and the two flashes are perceived as only a single flash. When varying the temporal offset of the two flashes in the fusion condition, older adults show no difference in their susceptibility to this illusion than their younger counterparts in this effect, even though an increased susceptibility in the fission effect was also observed at wider temporal discrepancies within the same subject group [70], replicating the previous flash illusion study [56]. Importantly, this study also showed that this effect was driven by a change in sensitivity (d') as opposed to response bias, which can also change in aging [70]. Similar results have been shown with the McGurk Effect, where age-related changes in the reported percept are accounted for by changes in perception specifically, as opposed to a more cognitively mediated response bias [71].

The coincident findings of declining temporal perception and multisensory integration in aging have led to the hypothesis that these two processes may be related. A number of recent findings have examined the link between these two processes within individual participants. The first such study employed both SJ and TOJ tasks to measure temporal processing [72]. Older adults showed poorer temporal acuity (greater TBWs) with the TOJ task but not with the SJ task. Additionally, participants also completed stream-bounce task, in which two visual circles are presented at opposite sides of a computer screen, and then move towards each other, overlap and cross, and proceed to the opposite side of the screen from which they started (See Figure 1D). This motion can be perceived in one of two ways, with the circles “streaming” passed each other, or “bouncing” off of each other and changing directions [68]. Importantly, when an auditory click or beep is played concurrently with the two circles overlapping, the “bounce” perception increases in prevalence, indicative of audiovisual integration. When older adults were presented with a temporal manipulation of this task where the presented sound was presented at various delays relative to the time at which the circles overlapped, they were found to have a larger TBW, indicating that there was a greater window of time in which they were susceptible to the “bounce” perception [72]. In younger adults, the size of the TBW in the stream-bounce illusion was positively correlated with the size of the TBW in the SJ task (and marginally so with the TOJ). However, both of these relationships were *not* observed in older adults, suggesting that the link between temporal processing and multisensory integration may be weaker in older adults.

A second study echoed and extended these results across the lifespan [8]. This study used a SJ task with simple flashes and beeps in individuals from 6 to 80 years old. These same participants also completed a McGurk task, where participants are presented with a visual token of a speaker articulating the syllable “ga” and a simultaneous auditory “ba” [66] (See Figure 1B). Participants often report perceiving the syllable “da” or “tha”, which was not presented in either modality. Results showed a narrowing of the TBW throughout development and into adulthood, confirming previous studies [21, 73], with a subsequent widening of the TBW with healthy aging. In the same subjects, an increase in the canonical McGurk percept was observed throughout development and into adulthood, followed by a decrease in healthy aging [8]. A regression analysis showed that multisensory temporal processing was predictive of the rate of McGurk perception in individual participants during development and into adulthood, but was *not* similarly predictive during the declines observed in aging. Therefore, although temporal acuity and multisensory integration are tightly linked during development and young adulthood, this link seems to be weakened during healthy aging. Although both temporal acuity and cognitive function show declines in aging, it is currently unclear if individual differences in temporal acuity are similarly decoupled with cognitive function or if decreases in temporal acuity may predict future cognitive impairment.

In addition to a widening of the TBW observed with aging, the overall plasticity of the TBW also appears to be affected [58]. Multiple studies have shown that the TBW typically adapts to reliable statistics of the environment, such that if one is presented with a continuous stream of asynchronous audiovisual stimuli, their perception of synchrony will shift towards the direction of that asynchrony (*i.e.*, towards either auditory-leading or visual-leading asynchrony), an effect known as temporal recalibration [74, 75]. In fact, this adaptation occurs even in surprisingly short time spans—even a single presentation of asynchronous stimuli can influence subsequent perceptions of synchrony [76-78]. One such study has recently been conducted comparing recalibration effects in younger and older adults using Gabor patches and pure tones [58]. While both age groups exhibited temporal recalibration, specifically when continuously presented with visual-leading stimulus pairs, this effect was reduced in older adults.

Perceptual learning is another measure of plasticity of the TBW. When participants are presented with active feedback about their performance, the TBW narrows, indicating improved temporal precision [79, 23, 80, 81]. One recent study has implemented such a perceptual-learning task in older adults measuring the TBW with a TOJ task [82]. Older adults did show benefits from this perceptual-learning task, as observed by a narrowing of the TBW. Importantly, the narrower an individual’s TBW following training, the narrower the TBW in the sound-induced flash illusion (smaller time window of illusory perception). Thus, while studies show that temporal processing and multisensory integration decouple during their concurrent decline in older adults [72, 8], actively improving temporal processing still influences integration.

The Influence of Stimulus Effectiveness

The effectiveness of unisensory component stimuli are typically inversely related to the amount of perceptual benefit associated with integrating the auditory and visual cues [1, 38], where effectiveness is typically experimentally manipulated through varying signal-to-noise (SNR) ratios. This pattern only holds up to the point at which an individual is able to extract meaningful information from a sensory input, or accumulate enough information to cross a decision threshold in, for example, a word-recognition task. Beyond this level the amount of behavioural benefit decreases, resulting in a pattern of behavioural gain where there is a “sweet spot” at which maximum gain occurs [49-51]. Indeed, there has been a good deal of evidence to suggest that the SNR at which maximal gain occurs during word recognition is relatively stable at adolescence [50] into adulthood [51], and across clinical populations [83-85].

Evidence has emerged over the last few years to suggest that the level of peak multisensory gain shifts with healthy aging. The first such study to address this presented individual words in the visual, auditory, and audiovisual modalities [86]. Words were embedded in auditory, multi-talker babble, and the auditory signal strength was parametrically varied to manipulate the SNR. In all modalities and all SNR levels, older participants were worse than their younger counterparts. Importantly though, the “sweet spot” at which older adults obtained maximum multisensory benefit was 12 dB higher SNR than the younger adults. It should be noted that this multisensory benefit was calculated relative to each individuals unisensory performance [64], ensuring that this difference was not due to known changes in unisensory processing with aging. While the “sweet spot” was different between groups, the magnitude of multisensory gain did not vary between groups. These findings suggest that, while the patterns of multisensory gain may change with healthy aging, the underlying mechanism may remain intact.

In this same study, data were analyzed at the phonemic level in addition to the whole-word level [86]. This analysis avoided two possible confounding explanations for the observed shift in the pattern of multisensory gain relative to SNR level. First, by measuring phoneme perception, participants did not have to accumulate enough perceptual evidence to cross a threshold required to correctly perceive a whole word but instead could receive credit for correctly perceiving some, but not all phonemes (*e.g.*, misperceiving “cat” as “cab”). Second, correctly perceiving a string of phonemes also requires more cognitive capacity, specifically working memory capacity. When analyzed at this lower perceptual level, older adults still performed worse than younger adults across modalities and SNR levels, but any differences between patterns of multisensory gain between groups disappeared. This seems to suggest that differences in multisensory integration of speech signals commonly observed in aging may be driven by cognitive, as opposed to perceptual changes.

A second recent study expanded on these findings, showing a similar effect at the sentence level [87]. In this study, participants completed a sentence recognition task in visual, auditory, and audiovisual conditions where sentences were embedded in multi-talker babble at parametrically varied SNRs. As in the previous study examining phoneme and word level perception [86] – the SNR at which older adults achieved maximum multisensory benefit was higher (less noisy) than younger adults, but there was no difference in the absolute

maximum benefit. This study, however, also included visual acuity and contrast sensitivity measures (an extensive battery of cognitive measures was also conducted, which will be addressed in the subsequent *Influence of Working Memory* section) [87]. Using multiple linear regression individual differences in perceptual and cognitive abilities were related to speech in noise perception. Visual acuity and contrast sensitivity were shown to positively predict the level of maximum benefit and the SNR at which this maximal benefit was observed, respectively, indicating that declines in visual perception may also be a driving force in changes in audiovisual speech.

While many speech perception tasks have manipulated level of auditory noise, varying the level of visual noise through blurring can also reveal interesting changes in multisensory perception in aging. In one such study, younger and older adults completed a word-recognition task where target words were embedded in sentences presented in the visual, auditory, and audiovisual modalities [88]. The level of auditory noise was kept constant at each participant's individually-measured SNR associated with 30% accuracy. As expected, visual blurring led to decreases in visual word recognition and, to a lesser extent, audiovisual word-recognition levels, replicating previous findings [89]. In a post-hoc analysis, perception was examined for each subject where the level of visual blur resulted in visual accuracy as close to 30% as possible. This held unisensory performance constant (30% accuracy) across both modalities for each participant so that audiovisual accuracy was then assessed relative to age alone without the confound of varying unisensory performance. In this analysis, no significant change in audiovisual word recognition was observed with age, suggesting that visual performance may also play a significant role in declines of audiovisual speech integration during healthy aging.

The contribution of visual performance to multisensory speech perception can also be extended to older adults exhibiting an increased reliance on visual cues with the onset of age-related hearing loss [90]. With an increased reliance on visual cues, the effect of any decrease in visual perception is likely to be exacerbated in audiovisual speech perception in older adults. With parametrically varied auditory SNR levels, perception of single syllable presentations in the auditory, visual, and audiovisual modalities was compared between younger and older adults [91]. Across all SNR levels, results showed that older adults were more influenced by visual stimuli. In a second experiment, the SNR was adapted to each individual to match auditory performance as opposed to matching physical stimuli. Still, the effect was the same, when compared to younger adults, older adults exhibited a stronger influence of visual stimuli. This latter comparison controls for age-related hearing loss, thus further isolating the contribution age-related changes in reliance on visual processing.

The Influence of Working Memory

Understanding speech in noise is difficult not only for the sensory demands placed on the perceptual system, but also its burden on working memory. In fact, when comparing measures' influence, working memory capacity (WMC) is one of the best predictors of performance on speech in noise tasks, second only to hearing loss itself [92]. Furthermore, there is an interaction of the impact of noise on speech perception and WMC such that

individuals with greater WMC are both less impacted by the presence of noise and show greater recall than those with smaller WMC [93-95].

Recent work has expanded upon this interaction [87]. As mentioned above, one particular study of speech-in-noise comprehension in aging varied both SNR and stimulus modality. Two dependent variables were examined, the SNR at which maximal gain occurred, and the level of absolute maximum gain. Age-related effects were only seen in the SNR at which maximal gain occurred. In addition to this behavioural protocol, they also conducted an extensive battery of cognitive tasks, including tests of processing speed, attention switching, inhibition ability, selective attention, and working memory. A multiple linear regression predicting the age-related change in the SNR at which maximal benefit occurred identified WMC as the only significant cognitive predictor. Greater WMC was associated with a lower (more noisy) SNR at which maximal gain was observed. Given the known decreases in WMC with age, these results provide strong evidence that cognitive decline, specifically declines in working memory, may influence task performance that is generally considered more sensory based – though it should be noted that perceptual and cognitive declines do not occur in isolation, and likely interact [96-98].

Indeed, a number of recent studies have suggested an interaction between WMC and age-related hearing loss. Using auditory, visual, and audiovisual versions of a classic N-back WMC task in young adults and older adults with normal hearing [99]. Participants were faster in the AV condition regardless of load, but showed the greatest multisensory benefit when WM load was highest, suggesting an interplay between WM load and multisensory integration. No age-related differences were found between younger adults and older adults with normal hearing. A follow-up study, however, included two groups of older adults, one with normal hearing and one with greater age-related hearing loss [100]. In a nearly identical paradigm, it was shown that older adults with poorer hearing benefitted more from the inclusion of visual information than did those with better hearing. And this difference between groups was greatest at the highest WM load. Thus, it appears not only that high WMC may influence multisensory integration of speech, but that multisensory integration of speech benefits WMC. One mechanism for this may be that greater WMC seems to allow for greater use of contextual cues to aid in speech perception, as shown by recent work investigating auditory-only speech perception [101] or auditory-only speech relative to visual text perception [102]. Research specifically targeting audiovisual speech integration is needed to confirm this hypothesis from a multisensory perspective.

Variability in Sensory Processing in Aging

One emerging area of research regarding healthy aging is concerned with not just differences in overall performance in healthy aging, but rather increased variability in executive and sensory processing. It has been well established that performance of aging adults decline on a number of cognitive tasks spanning multiple domains including working memory [103, 104], visuospatial abilities [105], and speed of information processing [106, 107]. Furthermore, more recent work has also highlighted age-related increases in intra-individual variability on a number of these tasks [108-110]. Far from being epiphenomenal, changes in intra-individual variability may both precede and predict future cognitive declines,

suggesting that this measure may represent an important predictive tool in the etiology of pathological aging [111-113]. It is currently unknown if intra-individual variability is domain general and observed across a wide range of sensory processing, or if it is more specific to certain kinds of sensory and multisensory processes.

Increased variability in aging has been observed across multiple stages sensory of processing. The auditory brainstem response (ABR) is a widely used measure of responsiveness to sound at the level of the auditory nerve and can serve as a test of sensory coding at the earliest stages of processing [114]. In older individuals, the ABR is not only delayed but also shows more variable timing in response to speech stimuli [115], echoing the decreased temporal acuity measured behaviorally for speech and non-speech stimuli in older individuals. This increased temporal variability is closely correlated with declines in performance on speech in noise tasks [116]. Farther along the processing hierarchy, greater variability in the blood oxygen level dependent (BOLD) response to simple (flashing checkerboard, finger tapping) and complex (audiovisual speech) stimuli has also been observed in older adults compared to younger adults [117-119]. In the one study that examined audiovisual stimuli in particular, increased variability was observed across both unisensory (auditory and visual ROIs) and multisensory (posterior STS ROI) cortex in older adults [117]. However, group differences in intrasubject variability were smallest in multisensory cortex—suggesting that multisensory processing may be able to partially compensate for declines in unisensory processing in aging. Importantly, these variability changes are seen in the absence of change in the mean amplitude of the response. Although this study presented clear audiovisual speech and therefore all subjects performed at ceiling, future work should examine whether intra-individual variability in multisensory speech areas correlates with individual differences in performance on speech in noise tasks to probe the relationship between neural variability and sensory processing.

Variability is an important factor to consider in the context of sensory processing-- if the brain's response to a particular stimulus is highly variable, it will be increasingly difficult to differentiate stimulus-evoked patterns of neural activity, leading to difficulty in processing and integrating sensory cues. Indeed, ongoing work has begun to provide evidence that high variability in older adults may make it more difficult to differentiate patterns of evoked responses [120], and the reduced fidelity of the neural response in healthy older adults may indeed be a mechanism that can account for poorer performance [121].

It is important to note that although variability can intuitively be understood as detrimental to processing and performance in many contexts, some kinds of variability, including cognitive flexibility, can underlie *improved* performance. Further, these different elements may differ across subjects based on variables like aging or the presence of disease, and they will also likely differ within the same subject based on specific task demands. In a study examining neural responses in a categorical speech perception task, it was hypothesized that decreased speech perception abilities might stem not only from weaknesses in early auditory processing but also from deficits in extracting information from auditory inputs along the cortical hierarchy [122]. They found that older adults had both poorer task performance (decreased discriminability between categorical speech boundaries) and greater variability in the evoked neural response when compared with younger adults. However, additional

analyses that examined the structure of this increased variability revealed that the older adults had decreased entropy of the EEG signal, suggesting a higher degree of redundancy in their neural representation of different speech signals. Echoing these findings, it has been shown that younger adults showed both decreased behavioral variability (more consistent reaction time responses) and increased neural variability (standard deviation of mean-block corrected BOLD time series) compared with older adults on a series of cognitive tasks [123]. More recent work has provided additional evidence that neural flexibility also seems to be reduced even during rest in healthy aging [124]. Together these findings point to the importance of moving beyond characterizations based on just the *amount* (e.g. high or low) of variability. In the future, examining the interplay of both flexibility and stability, especially with respect to known changes in the fidelity of sensory processing, will be especially important in unraveling the mechanisms of altered multisensory processing in aging.

Summary

Significant progress has been made in the last five years of research into multisensory integration in older adults. Changes in both bottom-up sensory and top-down cognitive processing appear to both play significant roles in changes in multisensory integration abilities in older adults. Although performance on many sensory processing tasks declines in healthy aging, like the ability to accurately perceive temporal relationships between sensory cues, performance on these tasks does not seem to be as strongly linked to multisensory integration abilities in older adults as it is in development. Additionally, the efficacy of the sensory signal has a differential impact with age, with maximum benefit observed with higher SNRs, though the level of maximal gain remains unchanged. However, individual differences in cognitive abilities like working memory are highly predictive of how well an individual can utilize contextual cues in ambiguous sensory environments like understanding speech in noise. Finally, examining both overall performance and performance variability may shed light on both the mechanisms of sensory processing declines in aging and predict future cognitive deficits.

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indicative of reduced neural flexibility) as well as increased variability across different networks.
[PubMed: 28473644]

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Figure 1. Methods of measuring audiovisual perception

Panel A depicts the experimental design for both the simultaneity judgment task and the temporal order judgment task. Visual and auditory stimuli are presented with parametrically varies stimulus onset asynchronies, and participants are asked to report either if the stimuli were synchronous, or which modality came first, with each respective task. *Panel B* depicts the McGurk task, where participants are presented with a visual token of a speaker articulating the syllable "ga" and a simultaneous auditory "ba". Participants often report perceiving the syllable "da" or "tha", which was not presented in either modality, and is

evidence of multisensory integration. *Panel C* depicts the sound-induced flash illusion, where an individual is presented with a single visual flash paired with varying numbers of auditory beeps, and instructed to count the number of flashes while ignoring the beeps. When the auditory and visual stimulus inputs are integrated, the presence of multiple beeps induces the perception of a second (or third) illusory flash. *Panel D* depicts the stream-bounce task. Two visual circles are presented at opposite sides of a computer screen, and then move towards each other, overlap and cross, and proceed to the opposite side of the screen from which they started. This motion can be perceived in one of two ways, with the circles “streaming” passed each other, or “bouncing” off each other and changing directions. Importantly, when an auditory click or beep is played concurrently with the two circles overlapping, the “bounce” perception increases in prevalence, indicative of audiovisual integration.