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The Potential of Multisensory Processing

Background

It has been shown that multisensory processing can have direct influence on unisensory processing through recent experiments carried out by Ladan Shams [1]. In the aforementioned study, the focus was directed toward audio-visual sensory modalities, three distinct experimental procedures resulted in three distinct insights: congruent multisensory stimulus pairings can facilitate unisensory learning; multisensory exposure can lead to unisensory recalibration; multisensory association learning can increase unisensory sensitivity. I will review each of the three areas focused on in Shams' study, and then go into detail about potential areas of research revolving around multisensory processing: Color Vision Training (CVT), the anatomy of multisensory processing, the use of Bayesian modeling, trisensory fMRI studies, Audio-Visual Entrainment (AVE) and Neuro Feedback Training (NFT).

Congruent multisensory stimulus pairings can facilitate unisensory learning

It is well established that a more accurate representation of the outside world can be obtained though multisensory integration, after all, we live in a multisensory world. It makes logical sense that the brain can integrate different sensory inputs. For example, when one is in a noisy room, the congruent visual input from the moving lips of your conversing partner increases the ability to distinguish the auditory input. Conversely, as shown in the McGurk effect [2], incongruent visual-auditory stimuli results in a decreased accuracy in the perception of the auditory stimulus. An fMRI study highlighting this congruency/incongruency effect by Calvert [3] defined the left Superior Temporal Sulcus as the brain region responsible for synthesizing auditory and visual speech signals. In 1967, Treichler [4] stated "people generally remember 10% of what they read, 20% of what they hear, 30% of what they see, and 50% of what they see and hear". Yet, although there was this generality, as indicated by Shams, there was not much scientific evidence for multisensory learning. The current study addressed *visual perceptual learning of motion-direction perception* by pairing an auditory stimulus with a visual stimulus. Individuals were trained in one of two conditions, either in an audiovisual-congruent condition (AVcong-trained), or a visual only condition (V-trained). It was shown that the AVcong-trained group significantly outperformed the V-trained group when tested *in the absence of auditory stimuli.* Furthermore, the AVcong-trained group showed both quicker and greater learning. To address the objection that learning solely resulted from the pairing with an auditory stimulus, a study by Kim [5] included an audiovisual-incongruent condition (AVincong-trained), and looked at direction-specific training effects. It was shown that significant learning performance only occurred in the AVcong group, and learning was greater in the trained directional conditions versus untrained directions. Additionally, it was found that the performance of the AVcong group on silent trials converged with the performance on trials where auditory stimuli was present. Suggesting that performance could be due to *alteration of multisensory representations* that are then aroused unisensorily [6]. These results support the statement that congruent multisensory learning can facilitate unisensory learning.

Multisensory exposure can lead to unisensory recalibration

Multisensory experiences give rise to a simultaneous and integrated perception consistently and often in every day life. For example, when at the movie theatre, the visual stimuli from the actors on the screen is combined with the auditory stimuli coming from the speakers on the walls to form one integrated perception [7]. The auditory stimuli (speech) is perceived as emanating from the visual stimuli (actors), when in reality, it is coming from a different causal stimulus. Furthermore, the films at the movie theatre are still pictures being shown at a rapid rate, the visual system integrates this and produces a fluid perception, while this event is sequential, it appears simultaneous. In a slightly different example, when typing, the visual stimuli of letters appearing on the monitor is paired with the tactile stimuli of pushing buttons on the keyboard to form one integrated perception. When an airplane flies overhead, the visual system gets input and accounts for the plane to be in one locality, while the auditory system suggests it to be in another. In this case there is no integrated perception, the visual stimulus detects the plane here, while the input of the auditory system places the plane there. Recalibration can be thought to be essential in the evolution and survival of man kind. Our ancestors had to be aware of their surroundings, in example, if one was walking in a dark forest, the auditory system might be hypersensitive and pick up subtle cues that can alert the suboptimal visual system that there is a tiger prowling in the bushes. In a modern day example, when driving, the visual stimuli of traffic flow is constantly changing and is partially reliant on gaze direction. Through the addition of an auditory stimuli (i.e., a horn) a quick recalibration can be made to create a new and accurate spatial representation of traffic flow. Multisensory integration allows for the perception of who is *around you*. One study that is famously coined *The Rubber Hand Illusion (RHI)* [8] clearly demonstrates the phenomena of cross modal recalibration between tactile and visual stimuli. The participant occludes one arm while receiving tactile stimulation to the occluded hand. Simultaneously, the participant receives visual input of a rubber hand being stimulated tactically in an identical fashion. It through the visual system that proprioception is recalibrated, the participant soon perceives the rubber hand as their own. Recent studies have shown evidence for a bimodal mechanism for visual information around a hand-centered coordinate system in peripersonal space [27]. Botvinick and Cohen [29] report that participants of the RHI 'have a sensation of touch' close to or even inside of the dummy hand. This is elaborated upon by Avillac [30], the integration of visual information from the dummy hand and tactile information from the occluded hand creates a single visuotactile perception which transfers the proprioception to the peripersonal space of the dummy hand. Botvinick and Cohen state that once the tactile, proprioception and visual inputs have been aligned with the dummy hand, complete recalibration has occurred and the participant will take ownership of the dummy hand. It is also reported how crucial temporal synchrony of tactile and visual stimuli is; once the cues become asynchronous, the illusion crumbles [29]. Makin [27-28] found the posterior parietal cortex to be responsible in the multisensory integration of information prior to illusion onset, while the ventral premotor cortex seems to be the brain area responsible in the multisensory representation of the dummy hand once the illusion begins, implicating the role of the ventral premotor cortex in *body ownership*.

Although we can see recalibration manifesting in every day life, can we support and investigate it at the perceptual learning level? A study by Wozny and Shams [9] systematically examined multisensory recalibration through auditory and visual stimuli in order to see if bisensory exposures can influence a subsequent unisensory exposure. White discs were shown on a black screen with or without auditory stimuli that emanated from the same casual location. The recalibration effect was found, and as oppose to the 4-11s it takes in the RHI for recalibration [31-32], this spatial-recalibration happened within milliseconds. If the visual stimulus was presented to the right of the auditory stimulus, the spatial discrepancy between auditory and visual stimuli (A-V) increased to the right of center. This shifted the perceived location of sound in the following unisensory auditory trial to the right, this effect also happens in the reverse condition. These findings clearly show *unisensory recalibration* as a result of multisensory exposure.

Similarly, recent advances in Neuro Feedback Training (NFT) and Audio-Visual Entrainment (AVE) have used self-recalibration techniques to align proper brain states. In NFT, subjects use sensory inputs to obtain a mental representation of ones own brain rhythms, which after substantial training, can be controlled to oscillate in a certain frequency band. AVE utilizes bursts of auditory and visual stimuli to entrain the brain to a certain frequency band. These techniques have been shown effective in a multitude of conditions: ADHD, OCD, Autism, Schizophrenia, Eating Disorders, Depression, and General Well Being.

Multisensory association learning can increase unisensory sensitivity

It is evident that "congruent multisensory stimulus pairings can facilitate unisensory learning", but question arises whether learning can also be achieved through *arbitrary* multisensory stimulus pairings. A study by Wozny [11] demonstrated that visual sensitivity is significantly increased when paired with an arbitrary auditory stimulus compared solely to a visual stimulus exposure. In one condition, participants were exposed to a 45º sinusoidal grading (V1) paired with a 350Hz auditory stimulus (A1) to create exposure (V1A1), and solely presented a 135º sinusoidal grading (V2) in the second condition to create exposure (V2). While keeping the gaze locked on a fixation cross, the task objective was to identify any changes of color in the fixation cross, which occurred in about 10% of the trials. Testing was done before and after stimulus exposure to determine if an arbitrary auditory association could facilitate visual learning. An *auditory-visual learning association* was found in that post-exposure learning was significantly higher in the V1A1 condition than that of V1 alone. Learning effects were then examined across different visual stimuli (V1:45º vs V2: 135º) while paired with A1 to determine whether the learning was dependent on sinusoidal grading orientation. Significantly higher performance was found in the V1A1 condition compared to the V2A1 condition, suggesting that the learning is visual-orientation specific. Conversely, learning effects were also examined across different auditory stimuli (A1: 350Hz vs A2: 925Hz) while paired with V1 to determine whether this learning was dependent on the sound frequency. No significant differences were found between V1A1 and V1A2, suggesting that the learning was independent of the frequency of the auditory stimulus. Associative learning is attributed to the repeated presence of an auditory stimulus paired with a specific visual stimulus. Future investigations pairing auditory stimuli of a larger array of frequency are necessary to explore this discrepancy further.

These findings were further supported through a similar second experiment where the sinusoidal gradings were replaced with *coherent dot motion.* The same methodology was used, creating V1A1 and V2 as the two exposure conditions. However, in this experiment, V2 was also tested post-exposure to see if context of presentation is the result of improved learning, and not the associative pairing of V1A1. In unison with the earlier findings, V1A1 showed significant learning performance over V1 alone. Additionally, associative learning was shown to be direction specific, as the earlier experiment was shown to be orientation specific. These findings indicate *learning* *a low-level perceptual association* and present themselves as natural phenomena of multisensory integration. Context of presentation did not play a casual role in learning, condition V1A1 scored significantly higher post-exposure in testing than condition V2, confirming that the multisensory association is what increased the unisensory sensitivity.

Color Vision Training

Through the previously mentioned studies carried out by Shams, Kim, and Wozny [1,5,7,9,11] it is shown that multisensory processing has direct influence upon unisensory learning and recalibration. I will address the potential for and possible limitations against Color Vision Training in respect to an auditory stimulus influencing visual perception. Wyszecki [12] found that the cone cells of the human eye have peak sensitivities to 3 specific wavelength ranges 'blue' (S~419nm), 'green' (M~531nm) and 'red' (L~558nm). All perceived colors are taken from an integration of these three cones, if you receive a 600nm burst to your eye, the photoreceptors 'green' and 'red' will produce the most output, and the perception of color will be 'red'. However, if a burst of around 480nm is administered, a 'blue-green' color will be perceived. The sensitivities of the cells integrate to form a color perception of the world around us [f. 1]. People with normal working vision can differentiate around 150 wavelengths, whereas approximately 1% of the population is Protanopic (red-blind) and limited to around 17 wavelength discriminations [13, f. 2]. Protanopics can not distinguish between the many hues that occur every 10-60nm, as those with normal vision can, as the 'red' L-cone is missing [12, f. 3-5]. Those with Protanomaly, however, have suboptimal functioning 'red' L-cones, because all 3 cones are still present, this may be the group where Color Vision Training can be most effective. The goal would now not solely be the utilization of the S-cone and M-cone in absence of the L-cone, but to increase the performance of the L-cone through training to a more optimal level. Multisensory perceptual learning tasks have found plasticity in primitive sensory features such as: spatial location, angle of orientation and motion directions [14]. Experiments done by Karni and Sagi [25] have shown a remarkable capability for plasticity in trained texture discrimination, maintaining improved performance levels for up to three years. Clearly these studies show plasticity in multisensory learning [11], although questions arise if adult photoreceptors have similar capacity for plasticity as primitive sensory features. It is possible, as color is a derived from a *low-level vision process* that integrates frequencies across the electromagnetic spectrum.

Although congruent wave frequencies are not possible due to limitations (558nm = ~ 6146953.405Hz), it could be possible to use the phenomena of *multisensory recalibration or multisensory association* to elicit subtle shifts in cone sensitivity, giving rise to different hue perception. In the case of multisensory association learning, the aim would be to evoke plasticity of the L-cone through pairing the visual stimulus with an auditory stimulus. For example, following the methodology laid out Wozny [11], two exposure conditions are created by using indistinguishable hues to the red-deficient observer (V1 and V2) as the visual stimuli, while one is paired with an auditory stimulus (V1A1), and one is presented in absence of auditory stimuli (V2). After repeated presentation of the two exposure conditions, if significance is to be found for Color Vision Training, increased sensitivity should result toward V1 versus V2. Implying the subject is able to discriminate between the once indistinguishable hues. In another example, opposed to the spatial recalibration outlined by Wozny and Shams [9], the aim would be color recalibration. In the case of someone who has Protonomaly, the saturation level of the L-cone produces dim perceptions of the color red. Graham [26] showed that the L-cone and S-cone have relatively the same levels of saturation sensitivity, as can be seen in [f.6]. Through this shared sensitivity, it may be possible to tap into the saturation discrimination of the S-cone to recalibrate the L-cone. Experimental procedures involving differing levels of exposure to saturation in combination with an auditory stimulus will have to be carried out to see if color recalibration has any validity. The principle of 'dual coding' [15] indicates that input encoded through multiple channels helps "circumvent" limited processing capabilities of a single channel. Arousal of visual perception from auditory stimulus is also possible, as shown in the phenomena of Synesthesia. Future investigations will have to obtain a better understanding of Synesthesia, and the mechanisms of multisensory processing to shed light on the potential of Color Vision Training.

Advances in Multisensory Processing

While precise neural networks are constantly being refined and retuned, the mentioned studies in the Rubber Hand Illusion laid out the groundwork for visuotactile integration, in the following studies, we will look at visuotactile matching. Some of the earliest research was carried out by Hadjikhani [16], who utilized PET on a visuotactile condition. Subjects were asked to determine whether a pair of spherical ellipsoids were matched on the basis of shape when presented visually, tactually, or bisensorily. In attempt to pinpoint the brain structure corresponding solely to matching, Hadjikhani exposed subjects to a purely unisensory conditions of touch-touch stimuli and visual-visual stimuli. He then parsed the information and found one region of overlap: the right insula-claustrum. The claustrum is known to receive and give projects from the various sensory systems [17]. This is in concordance with a non-human lesion study done by Ettlinger and Wilson [18], who speculated that the synthesis of multisensory information arose from cortical synchronization made possible through a relay-station, such as the claustrum. Conversely, neurons in the Superior Colliculus have been said to be bisensory or trisensory, containing a map of sensory space for each sense it responds to (visual, auditory, tactile) [18]. These maps have been established to overlap and register with maps in the premotor cortex [19], and coordinate information for appropriate orientations (i.e. eye saccades are controlled by the SC) [20]. These 'multisensory cells' have also been shown to increase activation *super-additively* when stimuli from two or more senses appear in close temporal or spatial proximity [21]. These same cells have been shown to lesson or eliminate activation when presented with an incongruent stimuli [22]. The additive or subtractive effects of multisensory have been well documented, and shown systematically through the recent experiments of Shams [1]. The next step is to identify the corresponding brain regions that give rise to these processes. Banati [23] followed Hadjikhani [16] with a PET study that also aimed to identify the neural mechanisms behind visuotactile matching. The tactile stimulus was a metal arc placed out of view, and the visual stimulus was to match the perceived shape of the arc to one of four pictures on a computer screen. In attempts to account for only the brain regions required for visuotactile matching, there was a visual-visual condition in which the subjects simply matched a separate picture of a metal arc to one of the four pictures on the screen. Through subtracting the resulting brain maps Banati showed activation of a network of regions: inferior parietal lobes, bilateral superior temporal sulcus, anterior cingulate, left dorsolateral prefrontal cortex, and the left insula-claustrum. The authors reasoned their study produced different activations due to the absence of the touch-touch condition in Hadjikhani's study, which could have produced a *sequential* comparison in that subjects were able to see the initial presented tactile stimuli, thereby creating both a visual and tactile representation of it. This could potentially cause the overlapping brain regions to be inaccurate. Both PET studies produced activation of the left insula-claustrum, greatly supporting its involvement in the matching process of visuotactile stimuli. Referring back to the studies by Makin [27-28], the posterior parietal cortex and ventral premotor cortex are involved in visuotactile integration. It is possible that the networking of these areas creates a bisensory visuotactile circuit.

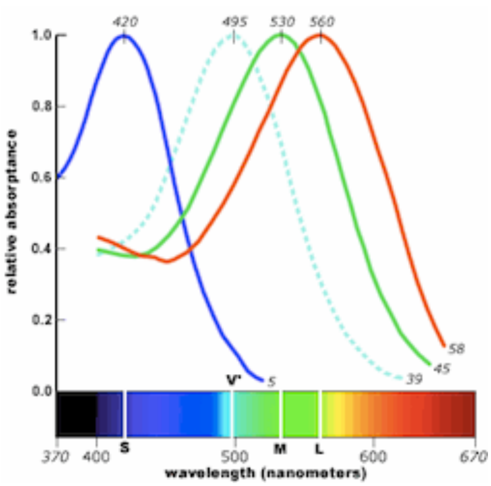
The proposed experiment builds on the foundation of Hadjikhani [16], Banati [23], Makin [27-28], Shams [1] and Wozny [24]. Wozny [24] examined trisensory processing by means of Bayesian modeling, for example, the change in the visual response between unimodal condition [V=1,A=0,T=0], bimodal condition [V=1,A=2, T = 0] and trimodal condition [V=1, A=2, T=2] may be either statistically insignificant or could correspond to a statistically significant alteration of visual perception by the presence of the auditory or tactile stimuli. A single model based on Bayesian interference was able to account at R2 = 0.95 for all of the outcomes across the possible permutations of the three modal conditions. This model gives extraordinary insight into multisensory processing and human perception. Future research can address trisensory processing through a similar systematic fashion while monitoring subjects brain behavior through imaging methods such as fMRI or electrophysiology methods such as EEG, illuminating the intricate structures of the brains sensory integration and matching processes.

One possible study could extend the concept of the PET studies by Hadjikhani [16] and Banati [23], and the fMRI study by Makin [28] by adding an auditory dimension. In this study the visual, tactile, and auditory cues will be synchronous, additionally creating synchronized proprioception; alongside baseline gustatory and olfactory sensations. For the visual stimulus, an orientation will be observed on a computer screen, such as the 15º line ' / '. The tactile stimulus would involve the subject placing their hand on a vibratory pad, which would induce a line of tactile stimulation in the 15º orientation. While the auditory stimulus would be given according to a calculated rise in pitch and frequency, resulting in the similar orientation when mapped on XY coordinates. Proprioception should be arranged so that the nuclei of perception is in orientation with visual perception. As shown in the *Rubber Hand Illusion*, orientation directly affects the responsiveness of peripersonal space cells, thought to be crucial in body ownership [27-28]. It is also crucial that this task has temporal synchrony, as failure for integration has been seen in asynchronous conditions [29]. This can be accounted for through the visual stimulus being 'drawn' from bottom-to-top simultaneously with a bottom-to-top tactile vibratory stimulation and a bottom-to-top rise in calculated auditory stimulus. The synchronization across modalities will provide insight into what regions of the brain encode multisensory integration, arguably the site of consciousness awareness through perception.

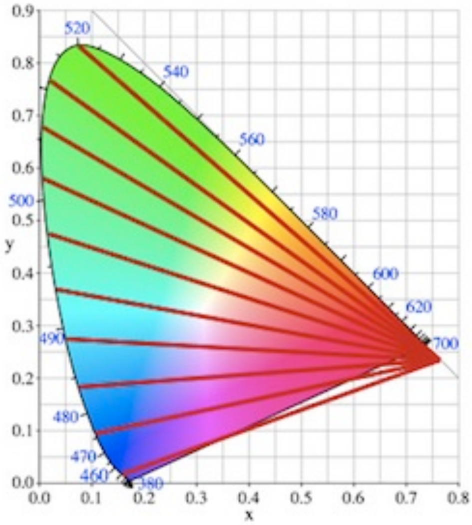
Slight changes to methodology can be explored to account for the center of consciousness. Representing the following findings through a 3D-motion representation of a qEEG readout, we can systematically alter the nuclei of perception and observe the influence on the nucleus of proprioception. The visual nucleus of perception is presented at fixation point (V1:0,0,0), displayed on a 3D representation of empty space, accounting for the distance between the observer and the screen, in an ideal condition, the visual nucleus would be present *in actual 3D space.* The auditory nucleus will be set to emanate from the (A1:0,0,0) coordinate in 3D auditory space. The tactile nucleus should be symmetrical to V1, one feasible example is to rest the hands on the keyboard with pointer fingers on 'f' and 'j' while touching the thumbs to create left/right hemisphere integration, sitting upright in a chair, with both feet firmly on the ground. Any condition where the tactile stimulus is symmetrical across V1 and has equal stimulation to the left and right hemispheres of the body is in alignment with the studies intentions. A sense of centered proprioception and peripersonal space arise through tuning to the point of *fusion* between the right and left perceptive fields of visual, auditory and tactile senses, V1, A1, T1; creating a centered conscious body awareness. Once the stimuli have been firmly established in the participants perception, shifts can be measured in each of the stimuli, and the influence on proprioception recorded. In example, shifting A1 a certain magnitude on the horizontal plane, creating A2. From what is understood about sensory recalibration, this shift in auditory stimulus will either be enough to significantly affect a shift in proprioception, or it may have to be greater or paired with a synchronized shift from V1 to V2 to significantly shift proprioception. Tests can be carried out in a variety of conditions. We can also measure effects of slight changes in tactile stimulus by shifting the participants hands from 'f' and 'j' to 'd' and 'h' while maintaining forward orientation, causing a slight imbalance in tactile sensation of the left and right hemispheres of orientation. In another example, we can utilize the *Rubber Hand Illusion* to distort the nuclei of proprioception through the creation of two distinct keyboard presentations [K1 and K2]. In K1, the subjects hands will be resting in the similar set up as T1, though in this case, the plane that the hands rest on will be lowered and occluded from view. In view, will be a set of dummy hands, K2 resting identically and directly above the occluded hands. I hypothesize that the spatial synchrony of the resting states of the three nuclei of presentation will cause a shift in total proprioception and peripersonal space toward the dummy hands. Contrasting the resting state of V1, A1, and K2 with that of V1, A1, and T1 should show distinct differences, in any conditions where one of the three stimuli is altered, there should also be differences. Understanding these differences is crucial for implicating the center of conscious awareness, hypothesized to be a *fusion* of all sensory systems.

Appendix

[f. 1] *Human photoreceptor sensitivity*.



[f. 2] *'Confusion Lines' in CIE XYZ colorspace*.

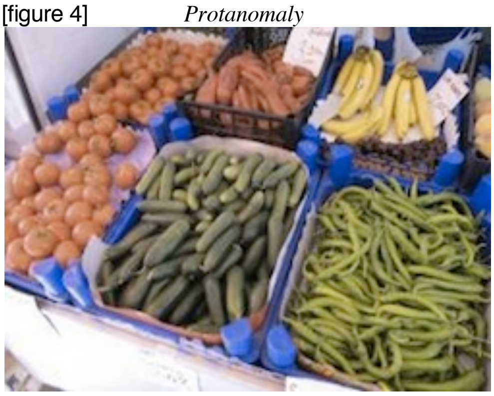


[f. 2]

In 1855, J. C. Maxwell said in reference to confusion lines… "Find two undistinguishable colors [for a colorblind person]. Mark them on the CIE diagram and draw a line through them. This line will connect all colors which can't be told apart by the colorblind person. You then can find more lines and all of those lines are either parallel or meet in a single point."

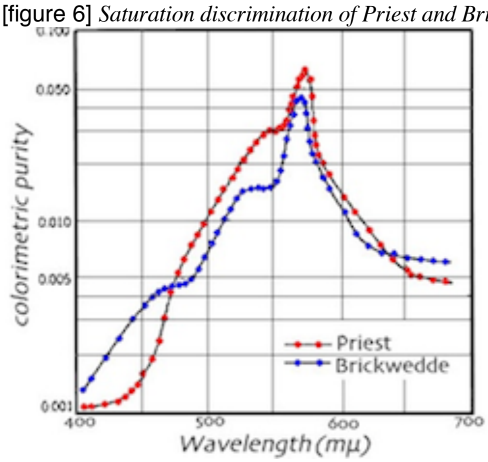
[figure 3] *Normal vision*

[figure 4] *Protanomaly*



[figure 5] *Protanopia*

[figure 6] *Saturation discrimination of Priest and Brickwedde*



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