Effective Tactile Noise Facilitates Visual Perception

J. E. Lugo**, R. Doti and J. Faubert

Visual Psychophysics and Perception Laboratory, School of Optometry, Université de Montréal,
C.P. 6128 succ. Centre Ville, Montréal, Québec, Canada H3C 3J7

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Abstract
The fulcrum principle establishes that a subthreshold excitatory signal (entering in one sense) that is synchronous with a facilitation signal (entering in a different sense) can be increased (up to a resonant-like level) and then decreased by the energy and frequency content of the facilitating signal. As a result, the sensation of the signal changes according to the excitatory signal strength. In this context, the sensitivity transitions represent the change from subthreshold activity to a firing activity in multisensory neurons. Initially the energy of their activity (supplied by the weak signals) is not enough to be detected but when the facilitating signal enters the brain, it generates a general activation among multisensory neurons, modifying their original activity. In our opinion, the result is an integrated activation that promotes sensitivity transitions and the signals are then perceived. In other words, the activity created by the interaction of the excitatory signal (e.g., visual) and the facilitating signal (tactile noise) at some specific energy, produces the capability for a central detection of an otherwise weak signal. In this work we investigate the effect of an effective tactile noise on visual perception. Specifically we show that tactile noise is capable of decreasing luminance modulated thresholds.

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Keywords
Multisensory integration, fulcrum principle, stochastic resonance

1. Introduction

Multisensory integration (MI) is a non-linear process that binds information from all the participating sensory stimuli. MI is a complex process in which our brain binds the different sensory stimuli that contribute to create a phantom image of the real world outside its perceptual limits. This image is the only reality we have. Researchers tried to define the human sensory stimulus span from threshold to ceiling.
They tested humans applying deterministic stimuli signals to the different senses. This generated normalized thresholds for auditory, tactile, visual, etc. From this, it was determined that if two weak (close to threshold level) stimuli are applied together, the presence of the additional stimulus facilitates perception. This happens for an elastic temporal coincidence. However, this perceptual improvement is not possible if one of the stimuli is clearly supra-threshold. This is known as the inverse-effectiveness law (Stein and Meredith, 1993). This means that perceptual enhancement takes place through the MI mechanism when we apply weak, supra-threshold, deterministic and coincident signals to the subject. However, there is an MI phenomenon that cannot be described by the inverse-effectiveness rule: cross-modal SR.

Stochastic resonance (SR) is a non-linear phenomenon whereby the addition of noise can improve the detection of weak stimuli (Moss et al., 2004). An optimal amount of added noise results in the maximum enhancement, whereas further increases in noise intensity only degrade detection or information content. The phenomenon does not occur in linear systems, where the addition of noise to either the system or the stimulus only degrades the measures of signal quality. The SR phenomenon was thought to exist only in stochastic, non-linear, dynamical systems but it also exists in another form referred to as ‘threshold SR’ or ‘non-dynamical SR’. This form of stochastic resonance results from the concurrence of a threshold, a subthreshold stimulus, and noise. These ingredients are omnipresent in nature as well as in a variety of man-made systems, which accounts for the observation of SR in many fields and conditions. The SR signature is that the signal-to-noise ratio, which is proportional to the system’s sensitivity, is an inverted U-like function of different noise levels. That is, the signal-to-noise ratio first is enhanced by the noise up to a maximum and then lessened. The SR phenomenon has been shown to occur in different macro- (Benzi et al., 1981), micro- (Simon and Libchaber, 1992) and nano-physical systems (Badzey and Mohanty, 2005) and neurophysiological systems (Ivey et al., 1998). Several studies have suggested that the higher central nervous system might utilize the noise to enhance sensory information (Moss et al., 2004). SR studies in humans can be divided into uni-modal SR (signal and noise enter the same sense) (Collins et al., 1997; Simonotto et al., 1997), central SR (signal and noise enters in similar local receptors and later mix in the cortex) (Hidaka et al., 2000) and behavioral SR (similar to central SR but its effect is observed in one sense and then enacted in the behavior of the subjects) (Kitajo et al., 2003).

Before the SR principle was proposed, Harper (1979) discovered what we currently would call cross-modal stochastic resonance while studying the effect of auditory white noise on sensitivity to visual flicker. Recently a similar result (Manjarrez et al., 2007) has been found where auditory noise produces SR when sub-threshold luminance stimuli are present. Furthermore, recently it has been shown that crossmodal SR is a ubiquitous phenomenon in humans because it involves different cortical areas and peripheral systems. For instance, under the same auditory noise conditions, the cross-modal SR is present among tactile, visual and proprio-
ceptive sensory systems (Lugo et al., 2008a). In another recent result it is shown that certain multisensory integration interactions (between deterministic auditory, visual and tactile signals) present a similar SR dynamics and the interaction is not only central but extends to peripheral systems (Lugo et al., 2008b). Therefore, these MI interactions (that involve deterministic and stochastic signals) allowed the introduction of a general dynamics model that involves the entire MI threshold enhancement. This non-linear model that handles deterministic or stochastic facilitating signals has been shown to be useful for explaining all the paradigms and we therefore call it ‘The fulcrum principle’ (Lugo et al., 2008a). The origin of the word fulcrum comes from *fulcire* to prop and specifically it has been described as the support about which a lever pivots. In its more general use a fulcrum is one that supplies capability for action and we believe that this best describes the fundamental principle at work in these multisensory interactions. In this sense the fulcrum represents a mechanism that supplies capability to extract information from the external world. The principle can be summarized as follows: a subthreshold excitatory signal (entering in one sense) that is synchronous with a facilitation signal (entering in a different sense) can be increased (up to a resonant-like level) and then decreased by the energy and frequency content of the facilitating signal. As a result the sensation of the signal changes according to the excitatory signal strength. The excitatory stimulus refers to the signal applied to the sense that we want to study. The facilitation stimulus means the signal applied simultaneously to the same subject, intended to trigger the MI mechanism in a way that facilitates the perception of the excitatory stimulus.

In this context, the sensitivity transitions represent the change from subthreshold activity to a synchronized firing activity in multisensory neurons. Initially the energy of their activity (supplied by the weak signals) is not enough to be detected but when the facilitation signal enters the brain, it generates a general activation among multisensory neurons, modifying their original activity. In our opinion, the result is an integrated activation that promotes sensitivity transitions and the signals are then perceived. In other words, the activity created by the interaction of the excitatory signal (e.g., tactile) and the facilitating signal (auditory noise) at some specific energy, produces the capability for a central detection of an otherwise weak signal.

The fulcrum principle may have numerous implications in a number of neurological alterations such as age-related neurodegenerative disorders like Alzheimer and Parkinson’s disease or other conditions such as strokes or spinal cord injuries. For instance, it is well known that the consequences of spinal cord injury or Parkinson’s disease are not just a break in communication between neurons; a cascade of events occur that promotes further neuronal degeneration, cell death and motor dysfunctioning (Horner and Gage, 2000). Locomotion training is a very effective tool in neuronal degeneration rehabilitation and regular locomotion exercises (or similar strategies) are associated with neuroprotective effects in different brain areas (Haas, 2008). Nevertheless, numerous patients are unable to do locomotion therapy and therefore the possibility of rehabilitation is reduced. Haas (2008) has
bypassed this problem by using vibratory stimulations, leading to reflex responses similar to reflex elicitations during human locomotion. He found that stochastic mechanical stimulations might be a useful method to counteract neuronal degeneration and to promote regenerative processes. Patients with Parkinson’s disease and spinal-cord-injury patients that were stimulated regularly in the lower extremities showed significantly improved postural control and locomotion abilities. Interestingly, treated Parkinson’s disease patients also showed reduced symptoms (tremor, rigidity) in the upper extremities. As improvements in manual coordination (e.g., writing performance) were confirmed in further standardized experimental setting, it seemed unlikely that this vibratory stimulation affected only the muscle or exclusively the peripheral nervous system.

In our previous studies we have used auditory stochastic noise, auditory and visual deterministic signals as facilitation signals. In this paper we investigate if the use of tactile noise may have an influence on visual luminance detection thresholds. Assuming the last experiment discussed above, and the fulcrum principle, there should be a facilitation effect. Prior to the experimental detail, we first introduce a non-linear model describing neuronal dynamics that will help us interpret the results.

2. A ‘Fulcrum’ Mathematical Model

Recently Martinez (Martinez et al., 2007) has investigated the effects of noise in the cat motor system. They modeled motor neuron activity by taking into account individual neuron responses. In our Fulcrum approach we will use a model that simulates neurons as natural devices with dynamics that consist of random low-amplitude motions (subthreshold neuronal activity) from which escapes occur at certain intervals (Simiu, 2002). The escapes are referred to as firings, and are associated with high amplitude bursts (spikes). In this way the effective multisensory neurons’ responses are determined by a bistable potential as in Simiu (2002). The master equation in our model is given by

\[ \dot{x} = -V'(x) + \epsilon [\gamma \cos(\omega_0 t) + \sigma G(t) - \beta \dot{x}] \]  

(1)

where \( x \) represents the neurons’ amplitude activity, \( \dot{x} \) is the neurons’ amplitude activity velocity (how their activity changes with time), \( V(x) \) is a double-well potential defined by a polynomial, \( \epsilon \) is a perturbation parameter that may have a stepwise variation over \( x \). \( \cos(\omega_0 t) \) represents the excitatory weak signal; \( G(t) \) is the facilitation signal and it can be a nearly white noise process or a deterministic one; \( \gamma, \sigma \) and \( \beta \) are adjustable parameters. The quantities between brackets represent excitatory, facilitation energy, and energy losses, respectively. Deterministic signals always present a limited bandwidth or a repetitive pattern. They can be described and recreated without error along the time domain. We know the evolution of the instantaneous energy transferred through these signals. Stochastic signals represent a random pattern and a very large bandwidth. We can establish the limits
of their characteristics (amplitude or bandwidth), but we do not know in advance their evolution along the time domain. We know the mean energy transferred through these signals. A good example of a stochastic signal is white noise (Papoulis, 1977).

Equation (1) can achieve simulations of neuronal time histories (with the appropriate parameter values) and it has solution with the qualitative features observed in the experiments described earlier. To achieve good neuronal time history simulations, the potential $V(x)$ must be asymmetric, which is deeper for $x > 0$ than for $x \leq 0$ as shown in Fig. 1(left column, top row).

### 2.1. Neuronal Firing Necessary Condition

Associated with an unperturbed system ($\varepsilon = 0$ for all $x$) are the homoclinic orbits $\Gamma^+$ and $\Gamma^-$ shown in Fig. 1(left column, middle row). In order for the escapes to take place we require that the maximum total energy produced during the motion over an entire homoclinic loop will be bigger than zero. Suppose the motion takes place on the unperturbed system’s homoclinic orbit. If the motion occurs over a small distance $\delta x_h$ ($h$ designates coordinates of the homoclinic orbit), then the maximum total energy is given by:

$$E_{\text{tot}} = E_{\text{loss}} + E_{\text{exc}} = -\varepsilon \beta \int_{-\infty}^{\infty} \dot{x}_h^2 \, dt + \varepsilon \int_{-\infty}^{\infty} \{ \gamma \cos[\omega_0(t)] + \sigma G(t) \} \dot{x}_h \, dt. \quad (2)$$

The condition $\max(E_{\text{tot}}) > 0$ gives the neuronal firing condition. This condition implies that the maximum of the second term between braces in equation (2) is larger than the first term (energy dissipation). Consequently, the energy of the system can drive the motion over the potential barrier and out of a potential well, that is, the neuron can fire.

### 2.2. Fulcrum Neuron Firing Condition

It is possible to show that the necessary condition for the fulcrum to occur (Lugo et al., 2008a), for the stochastic process $G(t)$, is

$$\left(-4\beta \sqrt{\alpha/3}\right) + \gamma S(\omega_0) + \sigma \sum_{k=1}^{N} a_k S(\omega_k) > 0,$$

where the constants $a_k$ are related to the Fourier one-side spectral density (Simiu, 2002). For a second harmonic signal $\sigma \cos(\omega_1 t)$ instead of white noise the conditions become:

$$\left(-4\beta \sqrt{\alpha/3}\right) + \gamma S(\omega_0) + \sigma S(\omega_1) > 0,$$

where $S(\omega_j) = (2/\alpha)^{1/2} \pi \omega_j \sec h\{\pi \omega_j / (2\sqrt{\alpha})\}$ is known as the Melnikov scale factor and it is visualized in Fig. 1(left column, bottom row). It is clear that if we want to optimize the energy transfer from the stochastic process $G(t)$ or deterministic process $\sigma \cos(\omega_1 t)$ then the spectral density of $G(t)$ needs to contain frequencies around the Melnikov scale factor maximum and the frequency $\omega_1$ from the signal $\sigma \cos(\omega_1 t)$ must be centered at the Melnikov scale factor $S(\omega)$ peak as well. The
Figure 1. Theoretical model for the fulcrum. (Left column, top row) Potential $V(x)$, where $x$ represents the neurons’ amplitude activity; (left column, middle row) Phase plane diagram showing homoclinic orbits; (left column, bottom row) Melnikov scale factor; (center column) shows the neurons’ spectrum amplitude as a function of the noise intensity, with intensity increasing from top to bottom. The insert (center column, middle row) shows the well-known SR inverted U-shape function. Right column shows neuronal firing histograms with their corresponding time histories. $T$ is the signal period and $N$ means the probability to have certain neuronal activity levels. This figure has been adapted from Lugo et al. (2008a) for clarity purposes.
central column in Fig. 1 shows the neurons’ spectrum amplitude as a function of the noise intensity \( \sigma \), with intensity increasing from top to bottom. As may be expected for low noise intensities, the energy transfer from the noise to the signal is not enough to achieve the synchronization and as a result the subthreshold activity dominates and no firings occur. However, as the noise intensity increases, firings also increase up to a maximum peak, where the mean escape rate approximately equals the signal frequency. Beyond this point, random firings can occur at different frequencies meaning that the synchronized energy transfer from the noise to the signal is destroyed and the signal is embedded in the subthreshold activity. The insert (center column, middle row) shows the well-known SR inverse U-shape function and its maximum peak. The right column in Fig. 1, shows neuron firing histograms with their correspondent time histories.

It is clear from equations (3) and (4) that if we increase the energy losses we have to accordingly increase the excitatory energy to always fulfill the fulcrum neuron firing condition. This means that the energy transfer is always fixed no matter how large the neuronal network is. From uni-modal and cross-modal SR studies this energy transfer can be inferred (Lugo et al., 2008a, 2008b; Ries, 2007; Zeng et al., 2000). The aforementioned studies have shown that auditory unimodal SR threshold minima happen between 3–5 dB (Ries, 2007; Zeng et al., 2000) below a point defined as noise threshold (Ries, 2007). The noise threshold is the point where the noise hinders the signal detection and the sensitivity worsens to levels above the noise threshold (the crossing point in the U-shape curve can be seen in Fig. 2(top)). If we take again the noise threshold as a reference for cross-modal studies (Lugo et al., 2008a) then we found that crossmodal SR threshold minima occur approximately in the same experimental range as the ones mentioned above where auditory noise was used as facilitation signal. We found that for visual experiments the minima are localized at \(-6 \pm 1\) dB (luminance stimulus detection) and \(-5 \pm 1\) dB (contrast stimulus detection). In the proprioception experiments the minima occur around \(-6 \pm 1\) dB and for tactile experiments at \(-8 \pm 1\) dB. For the interaction between a deterministic sound (facilitation signal) and a tactile signal (excitatory signal) the value was \(-4\) dB (Lugo et al., 2008b). In summary we can see from this model that, first, the nature of the facilitation signal is not important to promote neuronal firings, it can be stochastic or deterministic and second, the excitatory and facilitation signal inputs may be from the same sense (uni-modal interactions) or different senses (cross-modal interactions). So far, we (Lugo et al., 2008a, 2008b) and other groups (Ai et al., 2009; Manjarrez et al., 2007) have used auditory noise, deterministic sounds or visual signals to facilitate the enhancement of tactile, proprioceptive, visual or motor system performance. From these results we decided to explore the interaction between tactile noise and visual signals (luminance modulated stimuli) in humans. According with our model and the Haas results (Haas, 2008) the tactile noise should facilitate visual perception as well.
3. Materials and Methods

The study received ethical approval from the Institutional Review Board of the University of Montreal, Quebec, Canada. We performed psychophysical measurements in a sample of 7 healthy subjects (18–30 years old) with no history of tactile or visual or detectable neurological disorders. Vision was normal or corrected to normal (visual acuity of 6/6 or more). In all the experiments we applied different tactile noise intensity levels plus a baseline (no tactile noise) in randomized order (Fig. 2(bottom)). This randomized order of sessions assured that the observed effects are not simply due to a generalized modulation in attention/arousal. We maintained the intensity of the continuous tactile input noise constant for each session and varied it between sessions. We have measured absolute visual (in arbitrary units) thresholds and then normalized. Normalized visual thresholds were computed as follows: once the absolute threshold was obtained for different tactile noise conditions their values were divided by the absolute threshold obtained for the baseline condition. The experiments took place in a dark room. The tactile noise was presented by means of a specific designed transferred signal spectrum.

![Figure 2](image-url) (Top) Schematic showing the concept of noise threshold level. (Bottom) Experimental lay-out for the procedure is described in the text.
actuator (TSSA) that converted auditory signal spectrum energy into mechanical signal spectrum energy. The TSSA was designed to be used in different auditory applications and particularly to convert auditory energy into a mechanical vibration. A computer provided auditory white noise to an amplifier (Rolls RA62b). The TSSA was plugged into the amplifier. The subjects held the TSSA against their right internal metacarpus. Although the noise generation band and the electronic amplification band pass are wider than the auditory spectrum, the acoustic transducer of the TSSA drastically modifies the noise spectrum density because of mechanical and electrical resonances. That is the TSSA cannot reproduce the full white noise spectrum but still has an effective mechanical noise spectrum. We used a piezoelectric sensor (LDTM) with 10 kHz bandwidth to characterize the tactile noise provided by the TSSA. The tactile noise cut-off frequency was around 1 kHz and the maximum force we have used in the experiments was 18 mN. It is obvious that for any sensory stimulation the different processing stages required for the original noise to finally reach the cortex inevitably modifies the original white noise spectrum. This implies that the cortex interprets only a limited mechanical noise bandwidth with a cut-off frequency within 1 kHz (where its spectrum is possible attenuated) instead of a full white noise spectrum. Figure 3(top) shows an example of the auditory white noise power spectrum and the Fig. 3(bottom) shows an example of the effective mechanical noise power spectrum we used.

3.1. Visual Stimuli

To be consistent with all our previous experiments, we used first-order stimuli that are the sum of two terms: a luminance modulation given by:

$$L_{LM}(x, y) = L_0[M(x, y) + N(x, y)], \quad (5)$$

where $L_0$ represents the stimulus luminance average and the background luminance and $N(x, y)$ is an external carrier function. The function $M(x, y)$ is defined as:

$$M(x, y) = 1 + S(x, y), \quad (6)$$

where $S(x, y)$ is the signal. The signal function ($S(x, y)$) is a Gabor patch displayed in Fig. 4(top, left) with a center spatial frequency $f$ of 1 cpd, a standard deviation $\sigma$ of $1^\circ$, a phase $p$ randomized at each stimulus presentation and a Michelson contrast $C_{LM}$. $S(x, y)$ is given by:

$$S(x, y) = C_{LM} \sin(f r_i + p) \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right), \quad (7)$$

where $r_i$ can be the direction $x$ or $y$. The carrier function $N(x, y)$, shown in Fig. 4(top, right), generated a matrix of 320 times 320 pixels ($5 \times 5^\circ$), each element being randomly selected from a Gaussian distribution centered on 0.

In words, we define LM stimuli as the addition of an envelope (signal) with a carrier (texture) (Fig. 4(bottom, left)). Consequently, for LM stimuli, the local luminance spatial average varies throughout the stimulus according to the envelope while the local contrast remains constant (Fig. 4(bottom, right)).
The stimuli were presented using a 19-inch ViewSonic E90FB 0.25 CRT monitor with a mean luminance of 43 cd/m² and a refresh rate of 100 Hz, which was powered by a Pentium 4 computer.

The 10-bit Matrox Parhelia 512 graphic card was used in combination with the Noisy Bits method to make the screen luminance resolution perceptually equivalent to a continuous resolution (Allard and Faubert, 2008). The monitor was the only light source in the room. A Minolta CS100 photometer interfaced with a specific developed program calibrated the output intensity of each gun. At a viewing distance of 2.20 m, the width and height of each pixel was $\frac{1}{64}^\circ$ of visual angle.

3.2. Threshold Determination

In all the conditions, a 2-alternative-forced-choice method was used: every presentation contained a carrier modulated by a signal but the Gabor patch was either horizontal or vertical. The task was to discriminate between vertical or horizontal luminance-modulated stimuli. For a given task (detection of a LM signal), the signal and carrier modulation types were fixed and known to the observer. The stimuli were presented for 500 ms with stimuli intervals of the same duration. The spatial
Figure 4. (Top, left) Gabor patch signal. (Top, right) Gaussian noise. (Bottom, left) First-order stimuli. (Bottom, right) Spatial representation of the first-order stimuli.

window was circular with a full contrast plateau of 4° width and soft edges following a Gaussian distribution with a SD of 0.25°. After each trial, a feedback sound indicated to the observer if his response was correct. To evaluate thresholds, a 2-down-1-up procedure was used, that is, after two consecutive correct responses the dependent variable $LM \ C$ was decreased by 10% and increased by the same proportion after each incorrect response. The threshold was defined as the geometric mean of the last 6 inversions (peaks) of the dependent variable values. Participants were seated at a distance of 2.20 m of a calibrated computer screen and they had to decide whether the presented grating was horizontal or vertical. We measured the LM thresholds for the four tactile conditions (baseline plus three noise levels) in a random order. Ten thresholds (10 separate staircases) were established for each condition and averaged.
3.3. Data Analysis

The dependent variable of interest, the normalized visual threshold was analyzed by the method proposed by (Killeen, 2005) and used the $d'$ and the probability of replication $p_{rep}$, rather than $p$ values. The statistic $p_{rep}$ estimates the probability of replicating an effect. It captures traditional publication criteria for signal-to-noise ratio, while avoiding parametric inference and the resulting Bayesian dilemma. In order to calculate $p_{rep}$ we used the normalized threshold and its standard deviation as experimental inputs and a homogeneous distribution with average one and zero standard deviation as a control input. The experimental and control data numbers were ten for each case. With this information the effect size $d'$ and the standard deviation of replication $\sigma_{rep}$ are calculated. The probability of replication is computed by obtaining the probability of the variable formed by the ratio of $d'$, and $\sigma_{rep}$, assuming that such variable follows a standard normal distribution. In all the graphs, error bars represent one standard error. We used two criteria to decide where the SR peak was located in every subject. First, the SR peak was the peak that had the minimum value even if the U-shape function was not fully developed in the noise interval used. If there were two consecutive peaks we averaged their amplitude noise level values out. Second, the peaks had to have a $p_{rep} > 0.55$ (above the chance level). If the subject’s peaks did not fulfill the afore-mentioned criteria they were not taken into account in the analysis.

4. Results and Conclusions

Figure 5 shows the normalized visual LM thresholds for seven subjects. As in previous studies (Ai et al., 2009; Harper, 1979; Lugo et al., 2008a, 2008b; Manjarrez et al., 2007), the visual threshold profiles of the observers varied as a function of the different tactile noise levels demonstrating a typical U-inverse function. These results confirm our hypothesis that tactile noise could facilitate visual perception. We found that 5 of 7 subjects showed the facilitation effect while no facilitation was observed for two subjects. One possible reason for this is that the amplitude noise levels we used were not high enough to facilitate the task for these two subjects. This behavior has been observed before on auditory–tactile MI interactions (Lugo et al., 2008a). A second possibility is that the amplitude noise steps we used were too long and we may have missed the facilitation range in these two subjects. We have estimated the energy transfer in this interaction at $-7 \pm 2$ dB as is described in Lugo et al. (2008a) which is of the same order of magnitude than the other MI interactions described above.

The results presented here and in Ai et al. (2009), Harper (1979), Lugo et al. (2008a, 2008b) and Manjarrez et al. (2007) suggest a common neuronal processing mechanism for all the explored interactions. This does not mean that in all the cross-modal interactions that have been reported before or in this work the neuronal circuits are the same. Neurons may belong to different brain regions but they always follow the same physical principles. This is clear in our results because re-
Figure 5. Luminance modulated visual thresholds with tactile noise in seven subjects. Voltage amplitudes of 30, 63 and 140 mV correspond to force values of 10, 13, 18 mN, respectively. Error bars correspond to 1 SE. The black dots without error bars indicate $d'$ replication probabilities (right $y$-axis) and the broken line represents the 55% level.

Recently we have explored three different sensory systems and in one sensory system (visual) we have studied two different attributes corresponding to distinct mechanisms (luminance modulated signals and contrast modulated signals). Each system presented separate crossmodal SR characteristics but the SR minima were always in a similar range. Furthermore, there is evidence that the neuronal mechanisms involved in luminance and contrast modulated signal detection are different and that
contrast modulated signals involves more complex processing than luminance modulated signals (Allard and Faubert, 2006, 2007) but we nevertheless found similar SR characteristics (Lugo et al., 2008a). Furthermore, in all the crossmodal studies the noise was always auditory, which is different in this work where we use tactile noise. For these reasons, we believe that our results strongly support the notion that the Fulcrum principle is a fundamental physical principle that underlies all sensory processing. In the context of the fulcrum principle, the visual sensitivity transitions represent the change from subthreshold activity to a firing activity in multisensory neurons. Initially the energy of their activity (supplied by the weak signals) is not enough to be detected but when the tactile noise enters the brain, it generates a general activation among multisensory neurons, modifying their original activity. As a result there is an integrated activation that promotes visual sensitivity transitions and the signals are then perceived. In other words, the activity created by the interaction of the visual excitatory signal and the tactile noise facilitation signal at some specific energy produces the capability for a central detection of an otherwise weak visual signal.

From a neuroscience perspective we can hypothesize that the facilitation we observed in our experiments might be associated with the simultaneous activation of multisensory neurons in different brain regions once the tactile noise enters. For instance, Macaluso and co-workers (Macaluso et al., 2000) have tested the effect of simultaneous visuo-tactile stimulation on the activity of the human visual cortex and they have shown that a sudden touch on one hand can improve vision near that hand. Tactile stimulation enhanced activity in the visual cortex, but only when it was on the same side as a visual target. Analysis of effective connectivity between brain areas suggested that touch influences unimodal visual cortex via back-projections from multimodal parietal areas. That is, tactile information from the postcentral gyrus (i.e., contralateral somatosensory cortex) might thus be transferred to occipital areas (contralateral visual cortex) via back projections from parietal areas. This process depends on whether the visual and tactile stimuli are on the same side.

The fulcrum principle describes a ubiquitous process in humans related to how our peripheral and central systems use energy and frequency content of external and internal signals to modulate our perception of reality. We have seen that stochastic sounds or stochastic vibrations of one modality can facilitate perception of stimuli in another modality and underscore that they share the same dynamics. Consequently, no single sense normally works in isolation. These interactions may be the basis for explaining certain aspects of arousal dynamics related with the Yerkes–Dodson law (Yerkes and Dodson, 1908). At the same time they challenge us because they seemingly do not follow the inverse effectiveness law from classic multisensory integration theory. Finally, these results have obvious implications in developing methods for enhancing human performance in easy non-invasive ways. One possible application is with Parkinson’s disease as we have seen that stochastic vibrations applied to lower limbs not only enhanced mobility and decreased tremors in the same anatomical part where the vibration was applied but on the upper limbs.
as well (Haas, 2008). We now know that stochastic sound, under the right conditions, should also work. Potential applications could be for spinal cord and motor system injuries, memory, ADHD (see Söderlund et al., 2007) and age-related neurodegenerative diseases.

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