Homayoun Shahri

Examining Traumatic Memories: Re-encoding and Reconsolidation

Abstract

In this paper I will discuss a short review of traumatic memories based on neuroscience and information theory. Based on neuroscience and information theory, I will present a new technique that may rewrite the traumatic memories during reconsolidation. The presented technique is based on addition of new information at the time of recall of the traumatic memories which may result in re-encoding of these memories during the reconsolidation. The resultant rewritten memories seem to last for a very long time.

Keywords: neuroscience, trauma, memory, information theory, re-encoding, reconsolidation

Introduction

In a previous paper (Shahri, 2017), I discussed the nature of traumatic memories in detail. It is known that memories are a reconstruction of events at the time of recall. The converse is also true in that memories are recalled and remembered best when one is in the same situation or emotional state. It is important to note that emotions may affect the recall of certain aspects of memory more than others (LeDoux, 1996, 2002). It is also known that the memory of the more emotionally significant aspects of experience is remembered better than the more emotionally benign aspects of memory. Memories are known to be initially in a labile state and sensitive to change before becoming permanently encoded and consolidated in the neural pathways of the brain. It is observed that reactivation of consolidated memory can return it to a labile state again which makes the memory susceptible to change (re-encoding) during reconsolidation.

Memory, in its most general sense, can be defined as what we consciously recall from past events. But memory is more than what we consciously recall from the past (Siegel, 1999). In particular if a certain neural pattern has been activated in the past (in response to external or internal stimuli) then the probability of activating a similar pattern in the future is enhanced. This is how we remember and learn from the past. “The increased probability of firing a similar pattern is how the [neural] network remembers” (Siegel, 1999, p. 24). Siegel further writes, “Memory storage is the change in probability of activating a particular neural network pattern in the future” (Siegel, 1999, p. 25).

Our brain generally does not encode and save every experience as explicit memory, or else we would be inundated with so much information so that we would not be able to function. It seems that the more emotionally intense an experience is, the higher the probability of its

encoding and recall. The event is simply labeled as important by the amygdalae, which are parts of the brain involved in experiencing emotions. Likewise less emotionally intense events have a lower probability of being encoded and saved (Siegel, 1999). It is also important to note that events that are filled with fear, terror or are just overwhelming may not be encoded by the hippocampus, which is a part of the brain involved in memory and emotions. Several factors such as amygdala discharge, various neuroendocrines including noradrenaline and corticosteroids may inhibit the functioning of the hippocampus, thus blocking the encoding of the event and later recall. However, these events may be stored in implicit memory as fragments, while explicit memory is impaired (Siegel, 1999). Interestingly, when implicit memory is reactivated, it is not associated with a sense of time, place, and sense of self in time, nor is there a sense that something is being recalled. Implicit memory stores emotional dynamics of events, and not their contents. The brain can have implicit memory (mainly stored in the limbic system) from very early in an infant's life (and even prenatally). But it is only after roughly the second year of life that the hippocampus is developed enough to encode explicit memory.

It is important to note that emotional aspects of the traumatic memories are stored as implicit memories in the limbic system. There is thus a splitting off or dissociation of contents of the painful experiences from the emotional aspects of the experiences. The painful contents are repressed while the emotional dynamics are retained as implicit memories. As Shore (1994) indicated this splitting process is inter-hemispheric as well.

It is also important to mention that the recall of (degraded) past memories recovers some parts of these memories but may further augment these memories for meaning (elaborative repression), in an effort to reduce the uncertainty, and increase predictability in order to reduce

arousal (Erdelyi, 2006). For dissociated memories however, this same process may not occur, as these memories are highly state dependent and typically are not amenable to augmentation the way repressed memories may be. This is partially due to the nature of the dissociated memories that overwhelm various neuronal circuits and block the normal processing of these memories (Shahri, 2017).

In the next section, I will present a brief review of formation of and possible re-encoding of traumatic memories based on a neuroscience perspective.

A neuroscience perspective

The human memory formation is associative, which means that new information is remembered better if it is associated with previously encoded events or memories. The more emotionally meaningful the association, the more effective the encoding of the new information will be. Because of the associative nature of memory, encoding can be improved when new information is associated with other information already encoded in long term memory. This results in formation of a coherent narrative which is already familiar (Mastin, 2010).

LeDoux (1996, 2002) argues that the only memories that are unchanged are the memories that have never been recalled. When a memory is recalled it will go through changes. This is due to associativity of memory. Thus, when a memory is recalled, it will be associated with stimuli in the environment and then reconsolidated. LeDoux (1996, 2002) further argues that this gives us the opportunity to modify memories during the recall and reconsolidation.

In a recent study, researchers in LeDoux's laboratory, Daniela Schiller, et al (2009) indicated that during reconsolidation, memories go through a period of instability after being

recalled. The authors also introduce a behavioral technique for targeting the reconsolidation of fear memories in humans. They provide evidence that traumatic memories can be associated with benign information provided during the reconsolidation window. They show evidence that, as a consequence of this association, fear responses to traumatic memories are no longer expressed. They indicated that this effect lasted for at least one year and affected only the reactivated relevant memories without affecting others. The authors write (Shiller, et al, 2009): "These findings demonstrate the adaptive role of reconsolidation as a window of opportunity to rewrite emotional memories, and suggest a non-invasive technique that can be used safely in humans to prevent return of fear."

In a separate study from Joseph LeDoux's laboratory, Diaz-Mataix, et al (2013), write: "Traumatic fear memories are strong and persistent and form the basis of several pathological disorders, including post traumatic stress disorder (PTSD) and anxiety disorders. The search for procedures that may render these memories sensitive to pharmacological or behavioral treatments is thus critical. It is known that after memories have been consolidated into a long-term state they can enter a new labile state when reactivated prior to being reconsolidated. During this lability window, it is believed that memories are updated and new elements are incorporated." In this study, authors indicate that while in the labile state, the memories can be modified by introduction of new information during reconsolidation. This modification takes place due to associativity of memory which essentially indicates that recalled memory will be associated with the additional information during the reconsolidation and thus may modify the original fear-based and aversive memories.

In the appendix, I will introduce a short introduction to information theory which provides a different perspective into formation of traumatic memories as well a theoretical justification for their rewriting during reconsolidation. I will also describe, based on information theory, which memories are primed for recall and how we can employ results from information theory to possibly identify and arrive at relevant traumatic memories quickly. I strongly recommend that the interested reader review the appendix.

In the next section I will introduce a technique that seems to be highly effective in re-encoding and rewriting traumatic memories during their reconsolidation. This technique introduces additional information at the time of the recall of the traumatic memories to facilitate their re-encoding during reconsolidation. As I will show in the next section the additional information is the therapeutic relationship and connection.

Re-encoding of traumatic memories during reconsolidation

In the previous section I discussed a neuroscientific as well as an information theoretic perspective (See Appendix) regarding formation of traumatic memories. I also laid the theoretical foundation and groundwork for the technique that I will present in this section that may re-encode traumatic memories.

In this section I will describe a technique that may rewrite traumatic memories during reconsolidation. In my experience with clients, the rewritten consolidated memories have lasted at least for 7 months, and I have not yet observed their recurrence.

My approach for potential rewriting of traumatic memories is based on **adding new information at the time of the recall of the traumatic memory which can then result in its**

re-encoding during reconsolidation. The added information may results in rewriting of the traumatic memory so that it is more predictable (reduced information) and less emotionally significant. This re-encoding of high information content and emotionally charged memories results in conversion of these aversive memories, through elaborative repression (Erdelyi, 2006) to more predictable and less emotionally charged and benign memories. The efficacy of this proposed technique is predicated on a strong therapeutic relationship which functions as a predictable holding environment and a safe container.

I will present below, a brief history of the development of this technique. It was based on my own experience with my therapist, which led to the development of this technique that may rewrite traumatic memories.

Discovery of the technique

Late in 2016, in one of my sessions with my therapist (Bob Hilton), I wanted to work on an issue that was with plaguing me for years. I was feeling tensions in my lower back in the mornings. It felt like that I had to tighten my lower back in an attempt to withstand the pressures and stresses of what I had to do during a given day. I knew that this was not anything new and went back to my childhood. Bob asked me to lie down and he sat to my left and asked me to hold his hand. He then asked if I remembered the earliest memories of this contraction and holding pattern in my lower back. I replied that I believed I was 6 years old getting ready for school when I felt this tension in my lower back (possibly a fight between my psoas muscles contracting and my back muscles contracting to keep me standing up and straight). Bob then asked me to stay in contact with him. I did not fully follow his directive, and instead pictured

myself when I was 6 and moved my attention toward the contact with Bob and then toward observing myself when I was 6 in that contracted state. I was going back-and-forth between these two states. I noticed that the 6 year old (younger version of me) slowly changed to a more energetic, playful, and happy child. This experiment resulted in re-encoding of my memory of that time and the contraction in my lower back disappeared and has not returned since. I spent the next two weeks analyzing what had happened and also discussed it with Bob and mentioned my theory of why this rewriting happened. I mentioned to him that I modified what he asked me to do by alternating my attention between contact with him and to observing the feeling state for the traumatized child. I mentioned to Bob that it seemed like staying in contact while periodically switching attention to the traumatic memory can rewrite the memory, through elaborative repression, to one that is not as emotionally charged. In my earlier paper (Shahri, 2017), I had indicated that based on results from LeDoux's group it should be possible to rewrite traumatic memories, but did not know how to do it. My experience in my therapy with Bob presented the answer.

Results of the technique

I indicated above that our nervous system tends to move toward predictability and reduction of entropy. In my therapeutic session, the additional information was the safe and predictable therapeutic relationship which resulted in rewriting of the traumatic memories during reconsolidation to more predictable ones through elaborative repression. In the language of information theory the newly encoded memories have maximum (mutual) information and minimum conditional entropy. This means that my emotional state in the mornings became less

emotionally charged (lower entropy) given my traumatic experience of the past which was now rewritten to a more predictable memory.

I then applied the technique which was based on what had happened to me in my session with Bob Hilton to my clients with nearly complete success in the sense of re-encoding or rewriting of their traumatic memories that contained both developmental and shock traumas.

Application of the technique

In working with clients' traumatic memories related to developmental trauma, I sit across from them (Figure 3 a). When they discuss their presenting issue, I usually ask them about their earliest memories of a time that they felt this same way. Due to associativity of memory, and from an information theoretic perspective (See Appendix), the old traumatic memories are primed for recall and have a high probability of being remembered compared to irrelevant ones. I will then instruct the clients to imagine the feelings states and posture of themself at the time of the recalled memory and place their imagined self slightly to their left (to activate their right hemisphere) and in between themself and I (Figure 3 b). Activation of the right brain is important in keeping the clients in their feelings. It can be readily observed that if we look to the right, while not moving our head, it is easier to think about logical matters, but not emotional; while if we look to the left, we can think of emotional matters but it is difficult to think of logical ones.

I will then ask clients to take in and stay in contact with me and be fully aware of their connection with me. If clients don't fully understand how to stay in contact with me, I ask them to look into my eyes and be aware of the distance between us. I will then instruct the clients to

quickly look at their imagined self on their left for a fraction of a second (depending on the trauma, this period be may adjusted) and then come back to their connection with me. I reiterate to them the need to stay in contact and be aware of their contact with me, even when they look at their imagined self on their left. I also ask them to not think at all (to keep them more in their limbic system), and to simply stay in contact with me and periodically look at their imagined self. I ask clients after a couple of minutes whether their imagined self has changed in any way. I periodically mention to clients that they should avoid thinking and just stay in their limbic system where the timeless intrusive emotional memories reside. We will continue the exercise until a positive change occurs (usually a few to several minutes). When the change has occurred, I can usually observe it on their faces. When these early memories, which are the blueprint for many future behaviors, are re-encoded and rewritten, clients generally feel more free and do not function from their early traumas as often. Please note that Barlow's redundancy reducing hypothesis (Barlow, 1961) suggests that behavior, to a great extent, is based on earlier experiences, thus, when the adverse early memories are re-encoded, so are the future behaviors that are based on them.

Figure 3. (a) Staying with the therapist and (b) imagining the traumatized self to their left

Steps for working with shock and developmental trauma

The old memories may be related to actual events in shock trauma as in PTSD. In working with shock trauma, I work directly with the intruding memories. I ask clients to bring the traumatic memory to their attention as if they are watching someone else going through the trauma, and they (clients) are safe with me, so that they do not get overwhelmed or activated. I then, similar to working with developmental trauma, ask them to stay in contact with me, and while aware of our connection look at themself on the left for perhaps a quarter of a second (the stronger the emotions related to the intrusive memories the shorter the duration of staying with it), to activate their right hemisphere. I ask clients to see if an alternative story emerges (elaborative repression). We continue the exercise until a more benign and empowering story has emerged. Clients always know the real traumatic memory, but those memories no longer seem to trigger them, and instead the memories that seem to be of significance are then re-encoded and rewritten memories. The exercise usually does not last for than a few to several minutes.

In my practice, and over the last several months, I have worked with many clients and thus far, in every case, we have been able to successfully rewrite the traumatic memories and the old intrusive traumatic memories have not returned. In the following cases, I illustrate how I worked with two clients, one with shock trauma, and the other with developmental trauma. In both cases, the intrusive memories have not returned (as reported by clients). I worked with these clients six months prior to this writing, and there are no signs that these two clients are troubled by their former traumatic memories.

Case of Jenny

Jenny was a woman in her mid-thirties, who was referred by colleague. She came to see me to treat her severe anxiety. She was an educated woman and very driven in her work and life. She connected with me and we formed a strong therapeutic relationship fairly quickly. She then shared with me that she was sexually abused for several years by a relative and that she also had sleepwalking disorder. When I asked about the timing of the sleepwalking disorder, she indicated that it had developed shortly after the onset of sexual abuse. In the course of ongoing sessions, Jenny did several bioenergetic expressive exercises in order to own her anger and connect to her rage, during which some fragmented memories were recalled such the smell of the perpetrator. In our eighth session, I asked Jenny if she was willing to work on her trauma, and she replied 'yes'. I asked Jenny to stay in contact with me and be aware of connection with me at all times and look into my eyes. I then asked her to recall a memory that stood out in her mind related to the abuse, but that she did not need to share it with me (to avoid the possible shame), nor did she need to recall all the details but just a vague outline of the event (in order not to get triggered and retraumatized). I asked her to observe her younger self (placed on her left to activate her right hemisphere) in the recalled situation, as if she was watching a play, while staying in contact me. I asked her to remain aware of our connection and stay in contact with me and every few seconds look to left and observe herself in the past for only a fraction of a second, then come back to connection and safety of her contact with me. After several minutes, I asked Jenny to see if the narrative had begun to change. She mentioned that the narrative was changing and that in the new narrative, she called out an older adult who came to her rescue, and in a different situation, she kicked the perpetrator and ran away to safety. I asked her to stay in contact with me and to

see if the new narrative still held. She responded affirmatively, and indicated that she knew the original story but it seemed that what held truer was the modified narrative(s). In our next session she indicated that her husband had told her that she no longer sleepwalked, and said that her anxiety was reduced. She no longer suffers from sleepwalking disorder, and reports that she does not get triggered anymore by her traumatic past.

Case of Sally

Sally was a woman in her forties who came to see me regarding her anxiety and her low self-esteem. She was a bright and educated woman and reasonably successful in her career, but she always felt inadequate and like she constantly had to please others to gain their acceptance. She was constantly anxious that she was not good enough. I have worked with Sally for about a year. During the course of her therapy she developed a good understanding of developmental nature of her symptoms. She understood that she was neglected as a child (Sally was the second child among three sisters and a brother), and had to please her mom and dad to gain their attention. Most of the parents' attention went to the older sister, younger brother and her younger sister. Sally, in her therapy, had made much progress, but was still plagued by her entanglement with her parents and siblings. In a session, several months ago, I asked her to see if she was willing to try a new technique and she agreed. I asked her when her earliest memories of feeling neglected were. She answered that she believed that she was about six years old. I asked her to imagine herself as a six year old and pay attention to the feeling states and posture of the neglected six year old younger version of herself. I also asked her to stay in contact with me and place the younger version of herself (six year old) slightly to her left. I then asked her to describe the young girl. She mentioned that the young girl was sad, sullen, and was lonely with her head

down as if she was ashamed of herself. I asked Sally to look into my eyes, stay in contact with me and while she remains in contact with me to look at the six year old every few seconds for only half a second and come back to connection with me. After a few minutes, I asked Sally if the young girl was changing. She replied ‘yes’. I asked her how the young girl looked now. She indicated that the young girl’s head was no longer down, and that she was happier and more energetic, and was playing with her toys. After that session, Sally’s anxiety were reduced, she became much more empowered in her relationships and her self-esteem was much higher. After the passing of several months, Sally continues to have higher self-esteem and is less anxious and does not feel lonely anymore. She indicated a few months after our session that she knew her real story but when she was reminded of her childhood, the memory that came up for her was the memory of a happier and more energetic child, and not the sad, sullen, and ashamed child.

Conclusion

In this paper, I briefly reviewed the formation of traumatic memories based on neuroscience and information theory, and presented a new technique that may re-encode the traumatic memories during reconsolidation. I discussed the theoretical validity of my approach using neuroscience and information theory. I also presented two case vignettes to demonstrate how I apply this technique. Based on my clinical experience so far, it seems that the resultant rewritten memories may last for a very long time.

Acknowledgement

I would like to express my deep gratitude to Bob Hilton. The development of the technique presented in this paper would not have been possible without my work with Bob. I am indebted to him for listening to my theory and our discussion related to it, as well as his own ideas and theories. I would also like to express my deep appreciation for the constructive suggestions made by reviewers and editors of the journal.

References

Barlow, H. B. (1961). Possible principles underlying the transformations of sensory messages. Sensory Communication, Ed Rosenblith W., Ch13, 217-234 . Cambridge, MA:MIT Press.

Díaz-Mataix L., Ruiz Martinez R.C., Schafe G.E., LeDoux J.E., & Doyère V. (2013). Detection of a temporal error triggers reconsolidation of amygdala-dependent memories. *Curr Biol.* 23(6): 467–472.

Erdelyi, M.H. (2006). The unified theory of repression. Behavioral and Brain Sciences, 29, 499-551.

Hilton, R. (2008). *Relational somatic psychotherapy*. M. Sieck (Ed.). Santa Barbara, CA: Santa Barbara Graduate Institute.

LeDoux, J. (1996). *The emotional brain*. New York, NY: Simon & Schuster.

LeDoux, J. (2002). Synaptic self. New York, NY: Penguin Books.

Loh, L.K. & Bartulovic, M. (2014). Efficient coding hypothesis and an introduction to information theory. Retrieved from https://users.ece.cmu.edu/~pgrover/teaching/files/InfoTheoryEfficientCodingHypothesis.pdf

Mastin, L. (2010). The human memory. Retrieved from http://www.human-memory.net/processes_encoding.html

Pfaff D. (2006). *Brain arousal and information theory.* Cambridge, MA: Harvard University Press.

Pierce J.R., (1980). *An Introduction to Information Theory: Symbols, Signals and Noise*. Mineola, NY: Dover Publications.

Rieke F., Warland D., van Steveninck R.D.R., Bialek W., (1999). *Spikes, exploring the neural code.* Cambridge, MA: MIT Press.

Schiller D., Monfils M.H., Raio C.M., Johnson D.C., LeDoux J.E. & Phelps E.A. (2009). Preventing the return of fear in humans using reconsolidation update mechanisms. *Nature* 463: 49-53.

Schore, A. (1994). Affect regulation and the origin of the self. New York, NY: Psychology Press.

Shahri, H. (2017). Traumatic memories - a neuroscience perspective. Clinical Journal of the International Institute for Bioenergetic Analysis, 2017(27), 49-69.

Shannon, Claude E. (July 1948). A mathematical theory of communication. *Bell System Technical Journal*. **27** (3): 379–423.

Siegel, D. (1999). *The developing mind*. New York, NY: Guilford Press.

Appendix

An information theoretic perspective

Claude Shannon (Shannon, 1948) in his paper, 'A Mathematical Theory of Communication,' introduced the concept of information theory. According to information theory, the information contained in an event is inversely proportional to its probability of occurrence *p* (a number between 0 and 1). Thus the more likely the occurrence of an event, the less information the event contains. Conversely, the less likely the occurrence of an event, the more information the event contains. For instance, the sentence, 'there is at least one rainy day in a year', contains very little information since the presented assertion is very likely to be the case. But the sentence, 'it will rain tomorrow', carries much more information as it is less likely that it will rain tomorrow than having a rainy day in one year. Another way of stating the above statements is that events that are predictable contain less information, while unpredictable events contain more information.

Recently, there has been much interest in application of information theory in neuroscience (Pfaff, 2006; Rieke, Warland, van Steveninck, and Bialek, 1999). The neural connections via their axons and dendrites can be viewed and considered as communication channels with limited capacity. This indicates that the firing of neurons and the production of action potentials or spikes (Shahri, 2017) are governed by fundamental limits quantified by information theory. Figure 1-A below shows a discrete grid (marked by dots in the picture) laid over a picture of salamander fish which is used to measure the response of one ganglion cell (responding to darkness) of the salamander fish when moved on the discrete points of the grid. In this experiment, a ganglion cell which responds to darkness (cell in the retina) of a salamander

fish is placed over the location of the dots in the picture and then the response is measured. Figure 1-B shows the firing of the ganglion cell when moved across a column (over the location of the dots) marked by arrows. Figure 1-C shows the reconstruction of the captured image of the salamander based on the latency of the spikes (action potentials), that is the earlier the firing, the darker the actual scene is. Figure 1-D depicts the reconstruction of the captured image of the salamander based on the spike counts. One can appreciate that the sensory processing is limited by the firing of spikes. That is if the firing of ganglion cells cannot keep up with stimulus, the sensory information will not be encoded in its entirety and information will be lost. This argument is essential in the understanding of traumatic memory based on an information theoretic perspective. Namely, that when the sensory information is massive and beyond the capacity of neural firings (action potentials or spikes) to fully capture it, information is lost and the narrative related to the sensory stimuli can at best be preserved in fragmented and dissociated forms. Traumatic memories, in essence, are the memories that correspond to events that could not be captured and coded in their entirety due to fundamental limits on the rate of firing of spikes and action potentials. Furthermore, since a coherent narrative is not constructed that integrates the fragmented traumatic memories, these memories will contain high amount of information (unpredictability).

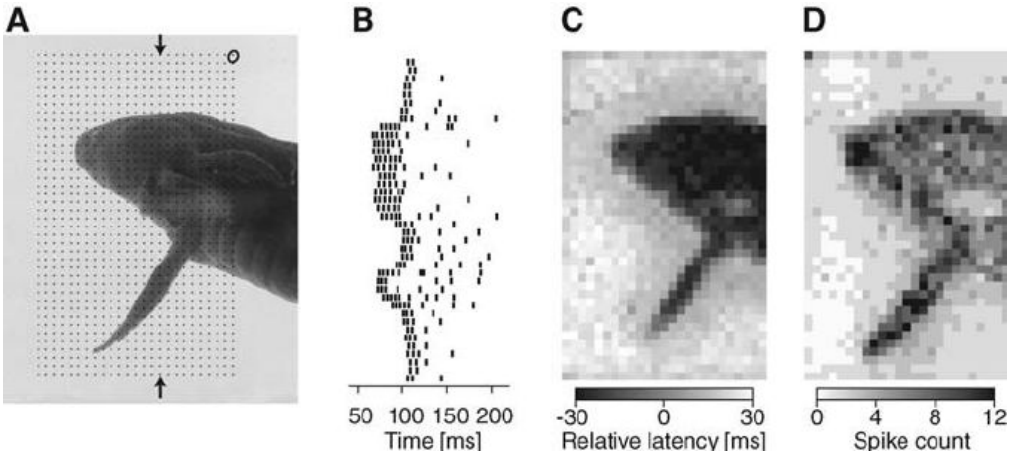

Figure 1. Response (Spikes) of Ganglion cell of a Salamander

This explanation immediately leads to a possible method of treatment for trauma. One can imagine that it might be possible to add information at the time of the recall of the fragmented memories to construct a narrative which combines the fragmented and partial-memories to form an alternative, benign narrative which encompasses most or all of the partial-memories.

In the following I will introduce an introduction to information theory, which is used to justify the technique for re-encoding of traumatic memories, presented in the next section. The reader may skip the mathematical formulas and only read the arguments. The formulas are introduced in this section only for completion and rigor.

Shannon (1948), quantified the information - *I* contained in the occurrence of an event with probability - *p* (a number between 0 and 1) according the following formula:

$$I = \log(1/p) \tag{1}$$

Where '*log*' is logarithm in base 2 (a quantity representing the power to which a fixed number - the base - must be raised to produce a given number - for example *log (1000)* in base *10* is *3* since *10* to the power of *3* is *1000*).

The information *I* is measured in bits. Shannon (1948) introduced the concept of "entropy". Entropy measures the information content of an event *E* which contains *n* outcomes. Entropy is simply the statistical average of information contained in occurrence of each outcome of event *E*. Entropy, *H* is defined as:

$$H = \sum_{i=1}^{n} p_i \log(1/p_i) \tag{2}$$

Where $\sum$ is the summation. For simplicity, one can write entropy of event X in a more concise fashion:

$$H(X) = \sum p(x) \log(1/p(x)) \tag{3}$$

Where *p(x)* is the probability of occurrence of an outcome of event *X*.

Shannon (1948), also introduced the concept of mutual information *I(X;Y)* which is a measure that indicates how much our uncertainty is reduced related to occurrence of event *X* given that a related event *Y* has occurred.

$$I(X;Y) = H(X) - H(X|Y) \tag{4}$$

And $H(X|Y)$ is the conditional entropy (uncertainty) of event X given that event Y has occurred. Mutual information is also measured in bits.

Shannon (1948), computed the channel capacity C as the maximum amount of information that can be transmitted through a channel. An implication of channel capacity applied to the brain sensory information processing is that the encoding of sensory information in the brain must be efficient and that neurons must be expressing their full output capacity in order to encode sensory information (with little loss of information) subject to the limits imposed by channel capacity. In the field of neuroscience and information theory this is known as the efficient-coding hypothesis. Loh and Bartulovic (2014) write: "The Efficient Coding Hypothesis, suggests that sensory relays recode sensory messages, so that their redundancy is reduced, but little information is lost. Coding to reduce redundancy eliminates wasteful neural activity, and also organizes sensory information such than an internal model of the environment causing the past sensory inputs to built up, while the current sensory situation is represented in a way that simplified the task of the part of the nervous system which is responsible for learning and conditioning."

Efficient-coding hypothesis which is also known as redundancy-reducing hypothesis was introduced by Barlow (1961).

Barlow's redundancy-reducing hypothesis (1961)

Horace Barlow (1961) argued that laws of nature are such that they bring order and simplicity to our complex sensory experiences. He further argued that the communication and coding of information in the brain should be fast, precise, and minimally redundant (efficient),

and should work regardless of the interference in the communication channel. The associativity of memories can be considered as a direct corollary of Barlow's hypothesis, in that by encoding associative information (memory) together redundancy is reduced in that memories are not encoded in separate and redundant parts. Another corollary of Barlow's hypothesis, which I will emphasize, is that when a memory is recalled, then all associated previously encoded memories are also primed for recall and thus have a higher probability of being recalled. Redundancy in information theory is defined as:

$$R = 1 - I/C \tag{5}$$

Where *R* is a measure of redundancy, *I* is mutual information, and *C* is the channel capacity, which is fixed and depends on the nature and characteristics of the channel. In the above formula it is clear that redundancy is minimized when mutual information is maximized, which essentially means that goal of nervous system is to maximize information about environment. We can readily observe that mutual information, *I(X;Y)* is maximized when the conditional entropy *H(X|Y)* is minimized. *H(X|Y)* is minimized when our uncertainty about the occurrence of event *X* is minimized given that event *Y* has occurred in the past. What the above statement says is that the conditional entropy *H(X|Y)* is reduced when Event *X* occurring in the present bears some resemblance to Event *Y* that occurred in the past. In other words when events *X* and *Y* are highly correlated *H(X|Y)* is minimized. Please note that the above also explains the phenomenon of transference which is about the repetition of behaviors retained from childhood toward a new object. It is also important to note that brain does not simply compute the correlation between sensory inputs corresponding to event *X* and all events *Y* that occurred in the past. It starts the computation with events that have higher information content and are thus more significant. Not

only do neuroscience and information theory prove this assertion, but also it is important to note that this would have had significant evolutionary advantages in that previously encoded events with high information content were generally more important and more relevant to the survival of our species.

A corollary of Barlow's hypothesis is that our nervous system moves toward predictability and avoidance of "high information" and unpredictability. Viewed somewhat simplistically, our brain can be thought of an information processing machine constantly trying to reduce the unpredictability of sensory input by correlating and comparing the sensory input to encoded events with high information content encoded that occurred in the past and finding the closest match, thus reducing the mutual information and reducing redundancy in encoding of the sensory input. Pfaff (2006) relates brain arousal and emotion to information and entropy, thus indicating that emotionally significant events contain more information and are more unpredictable. To illustrate this point, the interested reader could look at the checkered figures depicted on the right side of Figure 2, and notice which figure results in more arousal (attracts attention). As our vision is peripheral, figures that are more horizontal carry less information and have higher probabilities of occurrence and thus contain less information, while figures that are more vertical carry more information and have lower probabilities of occurrence and thus result in higher levels of arousal and emotional response. The figures on the left of figure 2 depict the firing of action potentials of ganglion cell of a Rhesus monkey. The interested reader should observe that ganglion cell of the Rhesus monkey responds with more spikes and action potentials to the vertical figure, and not as strongly to the horizontal figure, as Rhesus monkey's vision is also more peripheral.

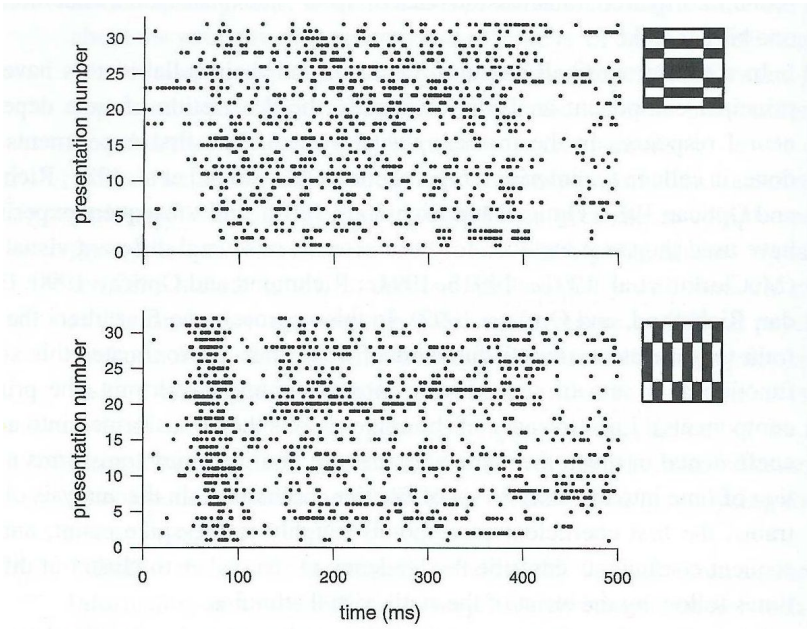

Figure 2. Rhesus Monkey's Ganglion Cell response to different patterns

As I discussed above in more detail, seen from an information theoretic perspective, traumatic memories correspond to events with high information that were beyond the capacity of firing rate of neurons to be represented and associated with previously encoded memory. The traumatic memories may thus be encoded as dissociated and fragmented part-memories that contain high amounts of information (unpredictability) and are more emotionally significant. These explain why traumatic memories are state dependent and can be easily triggered and result in emotional dysregulation. The treatment of trauma then requires the integration of highly emotional (high information) fragmented memories and reduction of their information content (unpredictability).

BIOGRAPHY

Homayoun Shahri, Ph.D., M.A., CBT, LMFT, received his PhD in electrical engineering specializing in coding and information theory from Lehigh University in 1990, and his master of arts in clinical and somatic psychology from Santa Barbara Graduate Institute (now part of The Chicago School of Professional Psychology) in 2012. He is a licensed marriage and family therapist, and has a private practice in Irvine, CA, USA. Homayoun is a Certified Bioenergetic Therapist, and is a member of the International Institute of Bioenergetic Analysis (IIBA) and the Southern California Institute for Bioenergetic Analysis (SCIBA). Homayoun is a member of the United States Association of Body Psychotherapy (USABP) and is on the peer review board of the International Body Psychotherapy Journal.

Email: homayoun.shahri@ravonkavi.com

URL: http://www.ravonkavi.com