

# The Tri-Transactional Theory of Stress: Theory Update and Birth of a New-Generation Stress Diagnostic Tool

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**Abstract** In this paper, I present an update version of the Tri-Transactional Theory of Stress without compromising its theoretical foundation. I eliminated confusion associated with the previously used stimulus objective intensity variable, replacing it by two new variables: Stimulus perceived intensity and individual sensitivity. As a result, the KTIRI-Stress equation developed in the latest versions of the theory is revised, and a simplified KTIRI-Stress accumulation equation was derived. By analogy with physics, I introduced a new concept called Stress Power (SP), which reflects the rate at which stimuli are converted into feelings of stress. This concept, together with the KTIRI-Stress accumulation equation, enabled us to enhance our understanding of the stress accumulation phenomena, in a manner consistent with prior research findings. Finally, the introduction of new variables and the revision of the equations helped us develop and present a prototype of a new-generation stress diagnostic tool, the KTIRI-Stimuli Diagnostic tool (KTIRI-SDT), presented in two variations. The implications of the study are thoroughly examined within the paper.

**Keywords** Tri-transactional theory of stress, Perceived intensity, Sensitivity, KTIRI-Stress equation, KTIRI-Stress accumulation equation, Stress power, KTIRI-Stimuli Diagnostic Tool

## 1. Introduction

### 1.1. The Tri-transactional Theory of Stress

In the theoretical study [1] of my Tri-Transactional theory of stress (Tri-TTS), which completes the Transactional model of stress [2], I introduced an additional dimension referred to as PSS (Previous State of Stress) and the notion of positive stimulus (PS). PSS was introduced to take into account an individual's state of stress before he or she encounters any type of stimulus (stressful or restful). Both factors are in fact necessary to consider in the assessment of the state of stress generated when facing an environment to which we can react positively (feeling relaxed) or negatively (feeling stressed).

In the original formulation of the Tri-TTS, the stress level experienced upon encountering a stimulus depends on three dimensions:

- PSS
- The intensity of the stimulus (denoted as SV, negative)
- The coping strategy (noted as R), if available, that is used to eliminate the effect of the stimulus

Its value, denoted as S, was presented in the form of the following proposed original equation [1]:

$$S = PSS + SV + R \quad (1)$$

However, the introduction of PS led us to put  $SV+R= ST$ , where ST could be positive (a positive stimulus) or negative. The equation was subsequently reformulated as follows:

$$S = PSS + ST \quad (2)$$

The second step of the development of the Tri-TTS was an empirical study [3]. I indeed found that the feeling of stress (positive or negative) occurred after facing one of the two types of stimuli used in the experiment (positive: relaxation and negative: mental arithmetic), depended on the previous state of stress (PSS).

However, if ST represents the intensity of the stimulus, its effect alone cannot be directly perceived, since the generated state of stress also depends on the PSS.

To address this issue, I asked the participants to evaluate, for each stimulus they had performed, PSS, the state of stress generated by the stimulus (S), and ST, redefined as the objective intensity of the stimulus rather than its isolated effect.

The results of the evaluations and their statistical analysis led to the following new structure of the stress equation [3]:

$$S = \alpha.PSS + \beta.ST + C, \text{ where} \quad (3)$$

$\alpha$ ,  $\beta$ , and C are constants

### 1.2. The Confusions

Nonetheless, although the results of the empirical study were consistent with the theoretical framework [1], asking participants to rate the objective intensity (ST) of the stimulus

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may lead to confusion or errors, namely:

- Although the objective intensity of the stimulus is the same for all participants under identical experimental conditions, not all of them can perceive it in the same way;
- Some participants may confuse the generated state of stress (S) with the objective intensity of the stimulus (ST).

### 1.3. Aim and Objectives

The aim of the present theoretical study is twofold:

- Updating the Tri-TTS while preserving its theoretical foundation;
- Refining the Ktiri-Stress equation to enhance its utility in psychological research and practice.

The related objectives are:

- Distinguishing between the real and perceived intensities of a stimulus, as well as their corresponding effects;
- Avoiding confusion between variables to be assessed in future empirical studies that apply the Tri-TTS on other population groups;
- Revising the Ktiri-Stress equation by integrating two variables: perceived stimulus intensity and the individual's sensitivity to the stimulus;
- Deriving a stress accumulation equation from the revised stress equation.
- Establishing that the predictions of the reformulated Ktiri-Stress accumulation equation are consistent with the findings of previous studies;
- Presenting a prototype of a new-generation stress diagnostic tool based on the Ktiri-Stress accumulation equation.

## 2. The Intensity and Effect of a Stimulus

### 2.1. The Experienced Effect of a Stimulus

Both early and recent studies refer to any influence (or event), which elicits a response (or activity) when talking about a stimulus. "It is any external influence that elicits a response" [4], or it is any external or internal event that triggers activity in the nervous system of an individual (Bhatia, 2009 as cited in Kim, 2019) [5] [6].

In my current study, a stimulus is defined as any internal or external agent interpreted by the nervous system as positive or negative, eliciting a response. It is internal if it comes from within us, such as thoughts, or external if it comes from the environment, such as noise. A negative stimulus can make a person feel stressed, but a positive stimulus can reduce the intensity of their stress, eliminate it, or even make them feel relaxed. Some examples of stimuli include noise, verbal aggression, joke, bad souvenir, rumination, soft music, relaxation technique, etc.

A stimulus possesses an intensity, measured in decibels (dB) in the case of noise, and can have an effect, which may

be perceived as strong or weak by an individual. Similarly, aggressive words interpreted as a negative stimulus within an individual's culture, may have a strong or weak effect depending on whether they are perceived as highly or moderately offensive. The elicited effect of a stimulus then varies depending on many factors, including individual characteristics such as sensitivity to the stimulus (see heading "3.1. Integration of Individual Sensitivity to the Stimulus (parameter  $\alpha$ )". Moreover, its effect alone is not always experienced. According to the version of the Tri-TTS currently being updated, the response elicited when encountering a stimulus then depends on three dimensions: the pre-existing feeling of stress (PSS); the stimulus intensity, influenced by individual sensitivity; and the coping strategy.

For instance, a noise of a certain intensity is not perceived by an individual if they wear noise-cancelling headphones (coping strategy available). Similarly, noise can be perceived if the individual is not wearing headphones or if they wear noise-reducing headphones. Additionally, if the same subject were already stressed ( $PSS < 0$ ), the intensity of their stress feeling would be higher if they did not wear headphones or if they wore noise-reducing headphones. Furthermore, two individuals perceiving the intensity with the same coping strategy can experience different sensations if they differ in their sensitivity to it. For more details about the noise stimulus and the use of the stress equation, see heading "5.1. Stimulus = Noise".

What an individual actually experiences when exposed to a stimulus is the state of stress generated by various factors (PSS, Sensitivity...) and not solely the effect of the stimulus itself.

### 2.2. The Objective Intensity of a Stimulus and Its Ambiguous Usage

In my empirical study [3], the aim was to show that the previous state of stress (PSS) was necessary to take into account when assessing the state of stress generated by exposure to a stimulus. I asked the participants to evaluate their pre-existing states of stress (PSS), the effect of each task, Relaxation and Mental arithmetic, considered as two types of stimuli and their states of stress experienced after performing both tasks.

However, because the only effect of a stimulus cannot be evaluated, see heading "2.1. The experienced effect of a stimulus", I asked the participants to evaluate the objective perceived effect of the stimulus, i.e. the objective intensity of the stimulus, denoted as ST. The study generated Equation (3) above, where ST represents the objective stimulus intensity.

Since the intensity of each stimulus (task) in the experiment does not change, it is expected to be perceived objectively by all participants. Indeed, the empirical study found that ST for two types of tasks (stimuli) were approximately constant across all participants [3]. Nonetheless, these results are not sufficient, as certain confusions may arise in future studies. Among these, the most likely to be made by future participants are:

- To confuse the intensity with the effect experienced
- To confuse the perceived effect of a stimulus with its true effect

To avoid any confusion, I will introduce new parameters and rewrite the stress equation without altering the core of the Tri-TTS, thereby preventing future participants from having to evaluate some unnecessary variables.

### 2.3. The Actual and Perceived Intensity of a Stimulus and their Respective Effects

We can categorize stimulus intensity into two types: actual intensity (AI) and perceived intensity (PI). The first represents the intensity of the stimulus regardless of the subject who perceives it, while the second one depends on the coping strategy used by the subject so that he or she will perceive it as either reduced or amplified. For example, if the actual intensity of a noise is 50 dB, the perceived intensity for a person wearing noise-reducing headphones will be less than 50 dB (40, 30 dB, etc.), not to mention their sensitivity to noise.

Likewise, the effect of a stimulus can be divided into two types: the actual effect and the perceived effect. The actual effect (AE) corresponds to its actual intensity (AI), which does not change by itself. The perceived effect (PE) corresponds to the effect generated by the perceived intensity (PI), influenced by individual sensitivity.

Using the same example of the noise of 50 dB, the experienced effect for a person not wearing headphones will correspond to the actual effect (AE). In contrast, the experienced effect will be lower than the AE-or even negligible-, if the person is wearing noise-reducing or noise-cancelling headphones. In both cases, however, the outcome also depends on the individual's sensitivity to noise (see heading "3.1. Integration of Individual Sensitivity to the Stimulus (parameter  $\alpha$ )).

## 3. Introduction of Two New Parameters ( $\alpha$ and $\beta$ )

Based on the stress equations (2), where the variable ST referred to the objective intensity of the stimulus, I will reformulate it by removing ST and incorporating the perceived intensity and the sensitivity parameter, denoted as  $\alpha$ . Another parameter, additional sensitivity ( $\beta$ ), will be considered and discussed, but its integration will remain implicit.

According to the Tri-TTS, the state of stress induced by a stimulus is a combination of the previous state of stress (PSS) and the stimulus-specific effect. This effect modulated by individual sensitivity and coping strategies, determines the perceived effect of the stimulus. The variable ST will then be replaced by PE, representing the perceived effect of the stimulus, see heading "2.3. The Actual and Perceived Intensity of a stimulus and their Respective Effects".

$$S = PSS + PE \quad (4)$$

### 3.1. Integration of Individual Sensitivity to the Stimulus (Parameter $\alpha$ )

When an individual encounters a stimulus and applies a coping strategy, (see heading "4. Encountering a Stimulus and Coping Strategies"), let us define the variable PI as the perceived intensity of the stimulus. The effect of this perceived intensity, however, may vary depending on the individual's sensitivity to the stimulus. To represent this effect, let us define a second variable, PE, such that  $PE = \alpha \cdot PI$ , where  $\alpha$  reflects the individual's sensitivity. It also represents, according to the relationship, the perceived effect per unit of perceived stimulus intensity ( $\alpha = PE/PI$ ). We then observe that the higher the value of  $\alpha$ , the greater the effect of the stimulus. Similarly, the higher the perceived intensity (PI), the greater the effect. Additionally, if a subject encounters a stimulus without using a coping strategy-meaning that the perceived intensity equals the actual intensity ( $PI=AI$ )-the stimulus will have no effect ( $PE=0$ ) if the subject is not sensitive to it (neither negatively nor positively), as if the stimulus does not exist, see heading "4. Encountering a stimulus and coping strategies". Likewise, if a person perceives a stimulus with a certain PI, their sensitivity to it remains constant during the exposure.

The total effect then scales with both how sensitive ( $\alpha$ ) a person is to the stimulus and the perceived intensity of that stimulus (PI) after applying a coping strategy.

Therefore, the perceived effect defined as the product  $\alpha \cdot PI$ , which models the interaction between  $\alpha$  and PI, represents a theoretically justified relationship. Accordingly, the Ktiri-Stress equation becomes as follows:

$$S = PSS + \alpha \cdot PI \quad (5)$$

The integration of the sensitivity parameter ( $\alpha$ ) is well justified. In addition to its usefulness in illustrating its role in understanding the causes of perceived effect, it is also consistent with findings from previous studies. These showed that individuals differ in how they process sensory stimuli. Additionally, more sensitive-to-sensory-stimuli individuals are more likely to exhibit heightened stress levels, whether the stimuli are internal or environmental (Redfearn et al., 2020 as cited in Harrold et al., 2024). [7] [8]. In the same vein, Yurchuk et al. reported that the sensitivity to stress depended, in addition to the characteristics of the stimulus (intensity, duration...), on the personal qualities of the individual (resilience, self-confidence, etc.) [9].

### 3.2. Consideration of Additional Sensitivity to the Stimulus (Parameter $\beta$ )

It is also important to mention another factor, which I consider significant and should not to be overlooked.

A previously stressed person (PSS not null) is expected to be more sensitive to stimuli. An additional parameter of sensitivity, denoted as  $\beta$ , which generates an added stress effect, should be considered in addition to the previous one (parameter  $\alpha$ ). It will be estimated null, if the person is not previously stressed ( $PSS=0$ ).

The consideration of this newly proposed parameter is consistent with prior research findings. For example, as reported by Das et al., stressed people cognitions are hypersensitive to criticism [10]. Similarly, deprivation of sleep increases individual’s sensitivity to stressful events and stimuli [11] and any work rhythm that results in prolonged periods of sleep deprivation can lead to increased resting cortisol secretion and activation of the Hypothalamic- Pituitary-Adrenal (HPA) axis, which is more sensitive to stressors (Minkel et al. 2014 as cited in Rippon, 2024) [12] [13]. In addition, people who are more sensitive to stress are also more influenced by positive environment [14].

At every point during exposure to a stimulus or combination of stimuli, an individual’s state of stress changes and becomes the baseline (PSS) for the subsequent response to continued exposure. And, given that  $\beta$  is dependent on PSS, it will also change over the course of exposure.

Therefore, the additional perceived effect of stress (APE) due to the influence of PSS on sensitivity will also change, either increasing or decreasing. I define it as  $APE = \beta.PI$ . See the example of the strike stimulus “heading 5.2. Stimulus = Strike”.

The parameter  $\beta$  actually represents the effect of the PSS on the individual’s sensitivity to a stimulus. For instance, if an individual is accustomed to a noise,  $\alpha$  is null, but if they are stressed they will be sensitive to the noise, and their total sensitivity will be  $(0 + \beta)$ . The parameter  $\beta$  then does not depend on  $\alpha$ , but on PSS and on the intensity of the stimulus.

Thus,  $(\alpha + \beta)$  represents the total sensitivity of a previously stressed person to a stimulus, with  $\alpha$  remaining constant and  $\beta$  varying during the exposure to the stimuli. I assume that the greater the stress state valence, the higher the total sensitivity.

The total perceived effect of stress if the person was previously stressed, is then  $PE + APE = \alpha. PI + \beta. PI$ . However, since the additional effect due to the additional sensitivity is driven by PSS, the latter and APE appear to be the same. Therefore, integrating both into the equation - rewritten as  $S = PSS + PE + APE$  - seems redundant. It is like saying “If I am stressed (PSS), I am more sensitive to the stimulus ( $\beta \neq 0$ ). My additional stress ( $APE = \beta.PI$ ), which originates from PSS, is a combination of APE and PSS”. This leaves us with two options, either integrate only PSS or only APE.

Nevertheless, we cannot claim that PSS has the same valence as APE. A person may experience high stress but still exhibits lower sensitivity. Similarly, it is uncertain whether a previously stressed individual will always be more sensitive than someone who has not experienced stress. Additionally, rather than being negatively stressed, a person might be in a relaxed state, which could make them less sensitive to a negative stimulus.

It is therefore necessary to explicitly mention PSS in the equation, and its mention is in fact an implicit acknowledgment of the additional sensitivity it introduces. This provides further evidence for considering the previous state of stress (PSS) and explicitly representing it within the

Ktiri-Stress equation as was postulated by the Tri-TTS theory [1] [3]. The new final structure of the Ktiri-Stress equation is then:

$$S = PSS + PE \tag{6}$$

OR

$$S = PSS + \alpha.PI \tag{7}$$

Accordingly, the state of stress induced by a stimulus or a combination of stimuli is determined by the combined effect of the previous state of stress and the perceived effects of the stimulus or stimuli.

### 4. Encountering a Stimulus and Coping Strategies

The level of stress induced by a stimulus is subject to individual’s differences [1] [2]. Its experienced effect depends on three dimensions, see heading “1.1 the Tri-Transactional theory of stress”, including the coping strategy used to reduce or eliminate the effect of the stimulus. Four distinct cases emerge in response to a stimulus:

Case 1: The person has learnt to ignore the irrelevant stimuli. This ability of learning is called “Habituation” (HA). This concept means that the sensitivity to a stimulus is decreased after repeated stimulation [15] [16]. In this case, the sensitivity parameter ( $\alpha$ ) is equal to zero, and as a result, the perceived effect is null.

Case 2: The coping strategy is not available (NACS). The person is exposed to the full intensity of the stimulus (perceived intensity=actual intensity).

Case 3: The coping strategy does not eliminate the effect of the stimulus, but reduces it. It is a stimulus-reducing coping strategy (SRCS). The individual is exposed only to a part of the stimulus’s actual intensity (perceived intensity < actual intensity).

Case 4: The coping strategy eliminates the full effect of the stimulus, as if the stimulus did not exist (perceived intensity = null). It is a stimulus-cancelling coping strategy (SCCS). This case is equivalent to case 1.

Combining PSS with these four cases results in twelve sub-cases when encountering a stimulus. The twelve different cases of the corresponding KTIRI-Stress equation are presented in Table 1.

**Table 1.** The 12 Cases of the KTIRI-Stress Equation when Encountering a Stimulus

Habituation	PSS					
	PSS=0 ( $\beta=0$ )			PSS#0 ( $\beta\neq 0$ )		
	Coping strategies			Coping strategies		
	SCCS	SRCS	NACS	SCCS	SRCS	NACS
HA* ( $\alpha=0$ )	0	0	0	PSS	PSS	PSS
NHA* ( $\alpha\neq 0$ )	0	$\alpha.PI$	$\alpha.PI$	PSS	PSS+ $\alpha.PI$	PSS+ $\alpha.PI$

\* HA=habituated individuals to the stimulus; NHA=non-habituated individuals to the stimulus

## 5. Illustrative Examples

This paragraph presents some concrete examples applying the KTIRI-Stress Equation developed above to clarify the terms introduced and the distinction between them.

### 5.1. Stimulus = Noise

Suppose a noise, considered a negative stimulus, with an intensity of 50 dB. A previously stressed person ( $PSS < 0$ ) encounters it and is not accustomed to it (NHA).  $PI_1$ ,  $PI_2$ , and  $PI_3$  represent the three perceived intensities corresponding to the following studied cases.

Case 1: Person not wearing headphones

- Actual intensity  $AI = 50$  dB
- Perceived intensity  $PI_1 = 50$  dB
- Sensitivity to  $PI_1 = \alpha_1$
- Perceived effect  $PE_1 = -(\alpha_1 \cdot PI_1) = -(\alpha_1 \cdot 50) < 0$
- Additional stress  $APE_1 = -\beta_1 \cdot PI_1 < 0$
- $S_1 = PSS + PE_1$
- $PE_1 < 0 \Rightarrow S_1 < PSS$

The noise caused the person's stress level to rise.

Case 2: Person wearing noise-cancelling headphones

- Actual intensity  $AI = 50$  dB
- Perceived intensity  $PI_2 = 0$
- Sensitivity to  $PI_2 = \alpha_2 = 0$
- Perceived effect  $PE_2 = 0$
- Additional stress  $APE_2 = 0$
- $S = PSS + PE_2$
- $S = PSS < 0$

The person's stress level has remained the same, as though the stimulus (noise) did not exist.

Case 3: Person wearing noise-reducing headphones

- Actual intensity = 50 dB
- Perceived intensity  $PI_3 < 50$  dB
- Sensitivity to  $PI_3 = \alpha_3 < \alpha_1$
- Perceived effect  $PE_3 > PE_1$  (the perceived effect is lower than in case 1)
- Additional stress  $APE_3 = -\beta_3 \cdot PI_3 < 0$
- $S_3 = PSS + PE_3 > S_1$
- $PE_3 < 0 \Rightarrow S_3 < PSS$

The noise caused the person's stress to rise, but to a lower extent than in case 1.

The level of stress an individual experiences upon hearing a noise depends on their prior stress level (PSS) and the availability of a coping strategy, which influences both the perceived intensity (PI) of the noise and the individual's sensitivity ( $\alpha$ ) to it. In addition, if the individual is habituated to the noise, it has no effect. This is as if it is perceived as nonexistent or because habituation acts like a coping strategy that eliminates its impact. Thus, the actual intensity of noise is not always perceived as it truly is, and distinguishing between them is crucial.

If the individual were not previously stressed (PSS and  $\beta$  are null), their level of stress ( $S = \alpha \cdot PI$ ) would be due only to the noise, as determined by its perceived intensity and the

sensitivity to it.

Previously stressed people and their reaction to noise have been the subject of experimental studies. In their research examining exposure to noise in relation to personality traits, Abbasi et al. [17] showed that neurotic students react strongly to noise. Moreover, as reported by van Kruijsdijk [18], neurotic people have increased stress levels compared to emotionally stable people.

If certain types of previously stressed individuals ( $PSS < 0$ ) are more sensitive to noise, as shown in these studies, the additional sensitivity  $\beta$  and its corresponding effect,  $APE = \beta \cdot PI$ , are different from zero (Case 1 and case 3). However, since it is unclear whether all stressed individuals are more sensitive to noise, it is more appropriate to reflect the additional effect in the PSS, which may or may not induce it (see heading "3.2. Consideration of Additional Sensitivity to the Stimulus (Parameter  $\beta$ )").

### 5.2. Stimulus = Strike

To enhance the understanding of the parameter PSS and the additional sensitivity  $\beta$ , I will present another type of stimulus that activates the sensory organ of touch. Let us take the example of a blow to the legs.

#### 5.2.1. Analogy with the Previous State of Stress (PSS)

If you hit a person on the leg, the perceived effect will be different depending on whether they are injured or not.

If the person is injured, their leg may be swollen or red. By analogy with states of stress, this prior condition of the leg can be described as negative. Additionally, the leg injury will increase the person's sensitivity to the hit, indicating that the additional sensitivity  $\beta$  and  $APE (= \beta \cdot PI_1)$  are different from zero. By analogy with the stress equation (6), the total effect felt, denoted as  $S_1$ , by the person after receiving the hit can be expressed as  $S_1 = PSS + PE_1$ , where PSS is the sensation associated with the pre-existing injury and  $PE_1$  is the effect of the hit (in the absence of injury).

If the additional effect due to the injury ( $APE_1$ ) is equivalent to PSS, the total effect can also be expressed as  $S_1 = PE_1 + APE_1$ .

The total effect  $S_1$  is then greater than in the absence of injury ( $S_1 = PE_1$ ), which is logically expected.

If we define  $S_1 = PE_1 + PSS + APE_1$ , this would be redundant, as it effectively states that the perceived effect after the hit is the combination of: the effect of the hit in the absence of the injury, the pre-existing effect due to the injury and the additional effect of the hit resulting from the injury. This is consistent with the earlier discussion regarding additional sensitivity and its overlap with PSS, see heading "3.2. Consideration of Additional Sensitivity to the Stimulus (Parameter  $\beta$ )".

#### 5.2.2. Analogy with the Perceived Intensity of Stimulus PI

If the person wears a protective bandage on their leg, the perceived intensity of the blow and the corresponding physical effect will change. The effect felt will differ from

that in the absence of the bandage. While the prior condition of the injured leg remains unchanged (PSS), the total effect felt after the hit will be reduced and can be expressed as  $S_2 = PSS + PE_2$ , where  $PE_2 > PE_1$ ; it follows that  $S_2 > S_1$ .

In this case, the additional effect due to the injury ( $APE_2$ ) cannot be considered equivalent to PSS, because the sensation of the injury under the bandage remains unchanged (PSS), whereas the bandage specifically reduces the additional effect. This provides further evidence that PSS does not always have the same valence as  $APE_2$  and must be explicitly expressed in the stress equation.

In this example, we distinguish between the actual and perceived intensities of the stimulus (the blow), depending on whether the person uses a coping strategy (the bandage) or not, see heading “4. Encountering a Stimulus and Coping Strategies“. Similarly, we distinguish between the perceived effect, which corresponds to the perceived intensity, influenced by individual’s sensitivity, and the generated effect, which also depends on the prior state.

### 5.3. Stimulus = Light

A similar interpretation could be made if the stimulus were light stimulating the visual sensory organs. By analogy with stress perception, if the person is affected, for example, by ocular conjunctivitis, this condition will correspond to the prior state (PSS). Therefore, the effect experienced in the eyes (S) after exposure to light can be expressed as  $S = PSS + PE$ , where,

- PSS is the effect due to the ocular conjunctivitis,
- PE is the effect of light in the absence of ocular conjunctivitis,

APE, in this case, is the additional effect resulting from increased sensitivity caused by ocular conjunctivitis.

If the person wears protective glasses, the same light will be perceived at a reduced intensity, and therefore the total experienced intensity will be diminished.

I conclude, based on the theoretical conceptions introduced above and supported by these illustrative examples, that the effect of the stimulus cannot be perceived in isolation. This is because an individual’s prior state of stress is, in most cases – or perhaps always- different from zero.

Therefore, I posit that a minimum level of stress is necessary to keep a person vigilant. Taking into account this minimum constant level of stress, denoted as C, I would rewrite the KTIRI-Stress equation presuming that the value of C varies between individuals:

$$S = PSS + \alpha \cdot PI + C \quad (8)$$

## 6. Stress Accumulation

I can define stress accumulation as the amount of stress received over a period, which can be either short or long. In this period, an individual can be exposed to multiple stimuli, both positive and negative, see heading “2.1. The Experienced Effect of a Stimulus“. Some of these stimuli may occur

simultaneously or successively, and each stimulus can last from a few seconds-like a disturbing car honk- to several hours, such as monotonous work.

### 6.1. A Case Illustrating Stress Accumulation

One day, after waking up in a bad mood (PSS negative) and having his breakfast, a man took the bus to get to work. The bus was crowded with people, which stressed him out (negative stimulus 1) during his 35-minutes ride. He hates his job, which he finds boring. Throughout the trip, he thought about it (negative stimulus 2). At work (negative stimulus 3) just before starting, he received some worrying messages (negative stimulus 4) from his friend, which he thought about for one hour. After that, he called his friend. The latter explained the meaning of the message. The man realized he had misinterpreted the message, which relaxed him (end of stimulus 4).

He finished his work (end of stimulus 3) and went home, making the same stressful trip for 40 minutes (negative stimulus 5). Back home, he felt very tired and slept for 2 hours (positive stimulus 6). When he woke up, he went to meet a friend at a café where he usually goes. Their discussion was pleasant (positive stimulus 7), during which they chatted and laughed.

In this example, the man was exposed to seven stimuli, five negative and two positive. Stimuli 1 and 2 were triggered simultaneously and lasted the same period. Stimuli 3 and 4 were also triggered simultaneously.

The following diagram (Figure 1) illustrates the above situation.

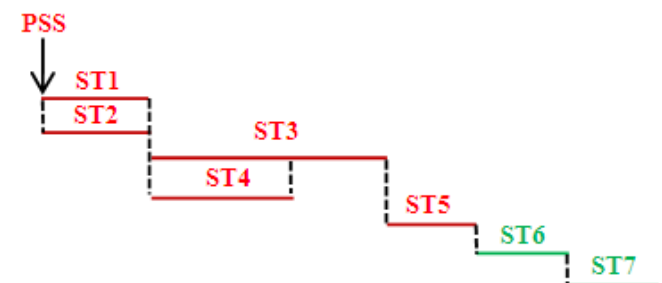


Figure 1. The seven stimuli and their respective durations

It seems that after leaving his friend, the stress accumulated by the man from the seven stimuli throughout the day could lead to a state of relaxation or result in only a slight sensation of stress. However, this cannot be definitively stated, since the outcome of the accumulation depends on the intensity and duration of each stimulus, as well as on his sensitivity to each of them and his stress level at the beginning of the day (PSS).

### 6.2. Calculation of the Stress Accumulation Equation

In this paragraph, based on the KTIRI-Stress equations (7 or 8) and using a simple stress accumulation situation (e.g. Figure 2), I will develop the stress accumulation equation. This development will be carried out using two approaches: the discrete summation approach and the continuous summation approach.

6.2.1. Example of a Stress Accumulation Situation

Suppose a person is exposed to two stimuli with actual intensities  $AI_1$  and  $AI_2$ , but whose perceived values by the individual are  $PI_1$  and  $PI_2$  (use of coping strategies). In addition,  $PI_1$  and  $PI_2$  are assumed to remain constant during the stimuli activation period, as are the corresponding sensitivities,  $\alpha_1$  and  $\alpha_2$ , given that the same individual is considered. The person, before encountering the first stimulus, was in a previous state of stress at  $T_0$  (PSS), which could be either positive or negative. The first stimulus was triggered at time  $T_1$  followed by the second one, which was triggered until  $T_3$  and both of them remained active between  $T_3$  and  $T_5$ . I can also describe the two stimuli as prolonged (e.g. Figure 2). Let us calculate the stress accumulation received by the person between times  $T_0$  and  $T_5$ .

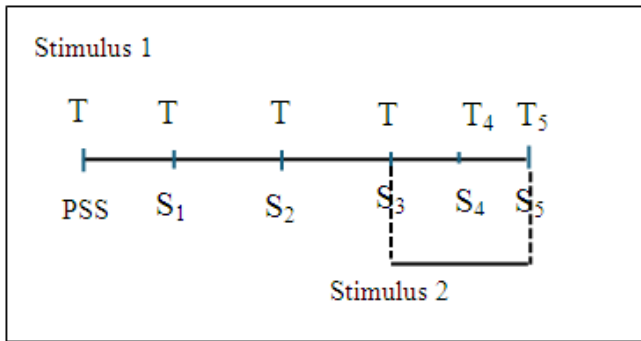


Figure 2. Exposure to two stimuli during discrete time steps

6.2.2. Discrete Summation Approach

In this approach, the individual’s state of stress is assumed to evolve in discrete time steps ( $T_1, T_2, T_3, T_4$  and  $T_5$ ) rather than continuously, remaining constant between any consecutive steps.

At time  $T_2$  for instance, the person's stress state ( $S_2$ ) depends on the previous stress state at  $T_1$  ( $S_1$ ), the perceived intensity  $PI_1$  of stimulus 1 and the individual's sensitivity  $\alpha_1$  to that stimulus. The additional sensitivities  $\beta_i$ , which depend on each  $S_i$ , are implicitly reflected in the values of  $S_i$ , see heading “3.2. Consideration of Additional Sensitivity to the Stimulus (Parameter  $\beta$ )”.

Between  $T_3$  and  $T_5$ , when the person is exposed to two stimuli- with  $\alpha_1$  and  $\alpha_2$  as their corresponding sensitivities- the parameter  $\beta_i$  actually represents the effect of  $S_i$  on the individual’s sensitivity to both stimuli combined.

Drawing upon the preceding data and applying the KTIRI-Stress equation (7 or 8), the successive stress states generated at each time step within the interval  $[T_0, T_5]$  can be formulated as follows:

$$S_0 = PSS \tag{9}$$

$$S_1 = PSS + \alpha_1.PI_1 \tag{10}$$

$$S_2 = S_1 + \alpha_1.PI_1 \tag{11}$$

$$S_3 = S_2 + \alpha_1.PI_1 + \alpha_2.PI_2 \tag{12}$$

$$S_4 = S_3 + \alpha_1.PI_1 + \alpha_2.PI_2 \tag{13}$$

$$S_5 = S_4 + \alpha_1.PI_1 + \alpha_2.PI_2 \tag{14}$$

I deduce that the stress accumulation denoted as SAC between time points  $T_0$  and  $T_5$  is given by the equation:

$$S_5 - PSS = 5.\alpha_1.PI_1 + 3 \alpha_2.PI_2 \tag{15}$$

OR

$$S_5 - PSS = 2.\alpha_1.PI_1 + 3.[\alpha_1.PI_1 + \alpha_2.PI_2] \tag{16}$$



The stress accumulation corresponding to the situation illustrated in Figure 2 is then the sum of the effect (stress received) of stimulus 1 during its activation period  $[T_0, T_2]$  and the combined effects of stimuli 1 and 2 during their joint activation period  $[T_3, T_5]$ . Moreover, if one stimulus is positive, such relaxation or laughter - or negative- such as noise or stressful work- its effect on stress will be positive or negative, respectively. Their interaction during the joint period  $[T_3, T_5]$  will be explained and illustrated by the examples below, see heading “6.4. Use of the KTIRI-Stress Accumulation Equation and Consistency with Previous Research”.

In general, if there are many small intervals, as illustrated in Figure 3, the stress accumulation equation between  $T_0$  and  $T_n$  becomes:

$$S_5 - PSS = (p-1).\alpha_1.PI_1 + (n-p+1). [\alpha_1.PI_1 + \alpha_2.PI_2] \tag{17}$$

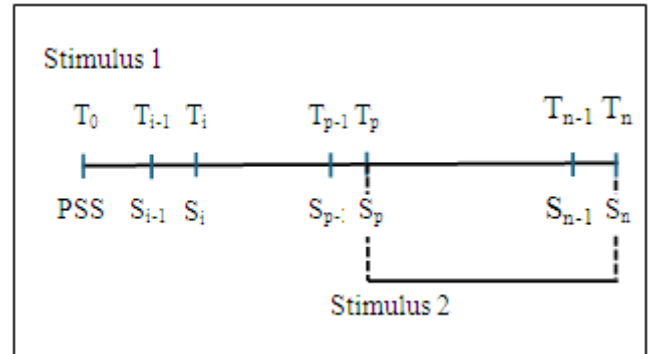


Figure 3. Exposure to two stimuli during n discrete time steps

In general, suppose a previously stressed individual ( $PSS = S_{T_0}$ ) is simultaneously exposed to  $m$  stimuli during the period  $\Delta t = T - T_0$ , divided into  $n$  small intervals. The stress accumulation induced by the  $m$  stimuli is given by:

$$S_T - S_{T_0} = n. \sum_{i=1}^m (\alpha_i.PI_i) \tag{18}$$

The stress accumulation received during the interval  $[T_0, T]$  is then expressed as the sum of the stress accumulations induced by each  $n$ -th stimulus over the same period.

6.2.3. Continuous Summation Approach

In this approach, I assume that the stress state  $S(t)$  of the individual varies continuously over the interval  $[T_0, T_5]$  (e.g. Figure 2). Consequently, any period during which the stress state remains constant is considered infinitesimal. In other words, the index  $n$  representing the number of periods tends to infinity.

I can therefore replace the number of periods within  $[T_0, T_3]$  by the quantity  $\Delta t_1 = T_3 - T_0$  and the number of periods within

$[T_3, T_5]$  by the quantity  $\Delta t_2 = T_5 - T_3$ .

Thus, the stress accumulation (SAC) equation between time points  $T_0$  and  $T_5$  takes the form of:

$$SAC = S_5 - PSS = \alpha_1 \cdot PI_1 \cdot \Delta t_1 + [\alpha_1 \cdot PI_1 + \alpha_2 \cdot PI_2] \cdot \Delta t_2 \quad (19)$$

$\longleftrightarrow$        $\longleftrightarrow$   
 SAC due to  $PI_1$       SAC due to  $PI_1$  and  $PI_2$

In general, if an individual is exposed to  $n$  stimuli during a period  $[T_0, T]$ , with  $PI_i$  and  $\alpha_i$  representing the  $i^{\text{th}}$  perceived intensity and sensitivity, respectively of the  $i^{\text{th}}$  stimulus—both assumed to be constant—the stress accumulation equation, called the KTIRI-Stress Accumulation Equation, is given by:

$$SAC = S_T - S_{T_0} = (T - T_0) \cdot \sum_{i=1}^n \alpha_i \cdot PI_i \quad (20)$$

OR

$$SAC = S_T - S_{T_0} = (T - T_0) \cdot \sum_{i=1}^n PE_i \quad (21)$$

Where:

- $S_T$  is the state of stress experienced at the end of the period,
- $S_{T_0}$  is the initial state of stress experienced at the beginning of the period,
- $PI_i$  is the perceived intensity of the  $i^{\text{th}}$  stimulus,
- $\alpha_i$  is the sensitivity of the individual to the  $i^{\text{th}}$  Stimulus,
- $PE_i$  is the perceived effect of the  $i^{\text{th}}$  Stimulus.

### 6.3. The Concept of Stress Power and its Utility

#### 6.3.1. Definition

I defined stress accumulation as the amount of stress received over a given period (see heading “6. Stress Accumulation”). This accumulated stress is, in fact, caused by the quantity of stimuli, which could be positive, negative or a combination of both, to which is exposed an individual. In other words, the amount of stimuli is transformed into a corresponding stress state.

In physics, power is defined as the quantity of energy transferred or converted per unit of time. In other words, it represents the rate at which energy is transferred or converted [19].

By analogy with this field of science, I define “Stress Power” as the amount of stimuli converted per unit of time. In other words, it is the rate at which stimuli are converted or transferred into stress sensations over a given time interval.

Stress power then describes the rate at which an individual’s stress level rises or falls over time. A more negative stress power implies a quicker onset of stress in response to negative stimuli, while a more positive value indicates faster recovery or relaxation.

#### 6.3.2. Calculation and Application of Stress Power

I define the stress power, denoted by  $SP$ , of an individual exposed to series of stimuli—positive, negative or both—, during a given period  $T$ , as:

$$SP = \frac{\text{Stress accumulation}}{T} \quad (22)$$

The introduction of the concept of stress power is highly

useful for understanding and quantifying changes in an individual’s stress response over time. First, if we know the number of stimuli an individual encounters daily, the concept of stress power can provide a general indication of the level of stress experienced per unit of time, see heading “7. Diagnosing an individual’s stress”. Second, it will allow us to demonstrate some stress phenomena caused by the deactivation of certain stimuli, which cannot be explained by the stress accumulation equation (see heading “6.4.5. The Impact of Stimulus Deactivation on Stress Accumulation”).

### 6.4. Use of the KTIRI-Stress Accumulation Equation and Consistency with Previous Research

In this section, I show that the KTIRI-Stress accumulation equation (20 or 21) can predict outcomes consistent with those reported in previous empirical studies. The following scenarios will be analyzed:

- 1- Prolonged Exposure to a Stimulus
- 2- Immediate Effect of a New Stimulus
- 3- Effect of Stimulus Intensity
- 4- Effect of Continuous Stimulus Activation on Stress Accumulation
- 5- The Impact of Stimulus Deactivation on Stress Accumulation
- 6- Effects of Ending a Negative Stimulus and Triggering a Positive Stimulus on Stress accumulation
- 7- Combination of Positive and Negative Stimuli
- 8- A Comparison between Single-Stressor Repetition and Multi-Stressor Exposure

#### 6.4.1. Prolonged Exposure to a Stimulus

Many studies have shown that encountering a stimulus during a certain period can generate increased stress. As reported by Peavy et al. [20], prolonged stress, in both humans and animals, leads to the activation of the stress axis, the Hypothalamic-Pituitary-Adrenal axis (HPA), which results in sustained secretion of stress hormones (glucocorticoid or cortisol in humans). Similarly, chronic exposure to physical and psychosocial stressors has been reported to adversely affect adult neurogenesis in many animal species [21]. This is also supported by a recent review study, which highlighted that chronic stress can lead to elevated cortisol levels through the activation of the Hypothalamic-Pituitary-Adrenal (HPA) axis, and is associated with adverse health outcomes [22].

All these findings show that prolonged exposure to stress (threatening stimuli) increases cortisol release and worsens the sensation of stress. The terms acute and chronic refer to the duration of stressors, which may range from minutes to hours in the case of acute stress, and from days to months in the case of chronic stress [23].

These outcomes can also be predicted using the KTIRI-Stress accumulation equation (20).

Suppose a person encounters the same stimulus with a perceived negative intensity  $PI$  ( $PI < 0$ ) and a sensitivity  $\alpha$  over the interval  $[T_0, T]$ . Let us demonstrate that the quantity of stress increases between the two time points.

If, at  $T_0$ , the initial quantity of stress is  $S_0 = PSS$ , then the stress accumulated between the two time points can be expressed as  $S - S_0 = \alpha \cdot PI \cdot (T - T_0)$ , where  $\alpha$  and  $(T - T_0)$  are positive. It follows that  $S - S_0 < 0$ , or equivalently,  $S < S_0$ .

The intensity of the stress state then decreases (becomes more negative). Moreover, the longer the period  $[T, T_0]$ , the more negative the accumulation of stress becomes.

#### 6.4.2. Immediate effect of a New Stimulus

In this section, I will examine the immediate effect of a stimulus.

Referring to the situation illustrated in Figure 2, let us imagine two scenarios in which, at time point  $T_3$ , an individual is either exposed to stimulus 2 ( $PI_2$ ) or not.  $S_3(2)$  and  $S_3(1)$  are perceived states of stress corresponding to the two scenarios, respectively. According to the KTIRI-Stress accumulation equation (20), the stress accumulated is

$S_3(1) - PSS = \alpha_1 \cdot PI_1 \cdot (T_3 - T_0)$  when stimulus 2 is not triggered, and

$S_3(2) - PSS = \alpha_1 \cdot PI_1 \cdot (T_3 - T_0) + \alpha_2 \cdot PI_2$  when stimulus 2 is triggered at  $T_3$ .

It follows that  $S_3(2) > S_3(1)$  if  $PI_2 > 0$ , and  $S_3(2) < S_3(1)$  if  $PI_2 < 0$ .

As predicted by the KTIRI-Stress and KTIRI-Stress accumulation equations, the stress response to a newly triggered stimulus is immediate and not time-dependent. It depends solely on the stimulus perceived intensity  $PI$  and the individual's sensitivity  $\alpha$ . The greater the intensity of the new stimulus, the more pronounced its effect, be it positive or negative.

In real-life situations, the immediate triggering of a positive stimulus ( $PI_2 > 0$ )-such as good news-can immediately reduce our sensation of stress. Likewise, if we receive a negative stimulus ( $PI_2 < 0$ )-such as reading an upsetting telephone messages-our level of stress increases immediately.

This outcome is also in line with previous experimental studies. Cettolin et al., examining economic rationality under stress, showed that though cortisol release takes time when an organism is exposed to a stressor, physiological responses begin within seconds [24].

#### 6.4.3. Effect of Stimulus Intensity

As demonstrated above (see heading "6.4.1. Prolonged Exposure to a Stimulus"), the length of stimulus activation period influences the magnitude of stress accumulation, assuming the intensity of stimuli remains constant.

In this section, I demonstrate that variations in stimulus intensity-whether increasing or decreasing-also influence the magnitude of stress accumulation.

Based on the scenario illustrated in Figure 2, the accumulation of stress- denoted as  $SAC1$  of an individual between  $T_3$  and  $T_5$ , where  $PI_1(1)$  and  $PI_2(1)$  represent the perceived intensities of the two stimuli, is given by:

$$SAC1 = S_5 - S_3 = [\alpha_1 \cdot PI_1(1) + \alpha_2 \cdot PI_2(1)] \cdot (T_5 - T_3) \quad (23)$$

If the individual were exposed to the second stimulus at a different intensity-denoted  $PI_2(2)$ , whether higher or lower-

the resulting stress accumulation denoted  $SAC2$ , would be given by:

$$SAC2 = S_5 - S_3 = [\alpha_1 \cdot PI_1(1) + \alpha_2 \cdot PI_2(2)] \cdot (T_5 - T_3) \quad (24)$$

The difference between the two stress accumulations is given by:

$$SAC2 - SAC1 = [\alpha_2 \cdot PI_2(2) - \alpha_2 \cdot PI_2(1)] \cdot (T_5 - T_3) \quad (25)$$

#### a) Higher intensity

a.1/ If  $PI_2$  is positive ( $PI_2(2) > PI_2(1)$ )

•  $SAC2 - SAC1 > 0 \Rightarrow SAC2 > SAC1$ : less stressed

a.2/ If  $PI_2$  is negative ( $PI_2(2) < PI_2(1)$ )

•  $SAC2 - SAC1 < 0 \Rightarrow SAC2 < SAC1$ : more stressed

#### b) Lower intensity

b.1/ If  $PI_2$  is positive ( $PI_2(2) < PI_2(1)$ )

•  $SAC2 - SAC1 < 0 \Rightarrow SAC2 < SAC1$ : more stressed

b.2/ If  $PI_2$  is negative ( $PI_2(2) > PI_2(1)$ )

•  $SAC2 - SAC1 > 0 \Rightarrow SAC2 > SAC1$ : less stressed

When individuals encounter positive stimuli with high perceived intensity or negative stimuli with low perceived intensity, stress accumulation increases in value (less negative)-reflecting a reduction in experienced stress (see a.1 and b.2).

Conversely, when individuals are exposed to negative stimuli with high perceived intensity or positive stimuli with low perceived intensity, stress accumulation decreases in value (more negative), indicating heightened stress levels (see a.2 and b.1).

This suggests that increasing (more positive) or decreasing (less positive) the perceived intensity of a positive stimulus produces effects comparable to those produced by increasing (less negative) or decreasing (more negative) the perceived intensity of a negative stimulus respectively.

For instance, imagine a person is in their office performing mentally tiring work (a negative stimulus) while talking to a colleague. Their level of stress is likely to be lower if the interactions with the colleague is pleasant (a higher positive stimulus). Similarly, the same individual would experience less stress if they were doing less mentally demanding work (a lower negative stimulus) while having a typical conversation with the colleague.

These outcomes predicted by the equations are consistent with previous research. As noted by McCormick et al. in their study [23], other aspects of stimuli- in addition to duration- such as intensity and frequency should also to be considered as they can affect the outcomes of stress. Consistent with this, Ardiyansyah et al. [25] demonstrated that the impact of noise on stress is linked to its intensity. The higher the intensity, the greater the release of cortisol. Furthermore, when noise exceeds a certain threshold, it can trigger physiological responses such as elevated blood pressure and increased pulse rate. In the same vein, an empirical study using virtual reality technique exposed participants to low- and high-intensity conversations with a customer avatar. The results showed that salivary cortisol levels were higher in the high intensity compared to the low-intensity group [26].

6.4.4. Effect of Continuous Stimulus Activation on Stress Accumulation

Referring to the situation illustrated in Figure 2, where the effects of stimuli 1 and 2 ended at  $T_5$ , let us imagine two cases where one of the two stimuli remains active after  $T_5$ . The stimuli 1 and 2 are assumed to be negative ( $PI_1 < 0$ ) and positive ( $PI_2 > 0$ ) respectively.

Case 1: The negative stimulus remains active until  $T_6$ , while the positive stimulus 2 ends at  $T_5$  (e.g. Figure 4)

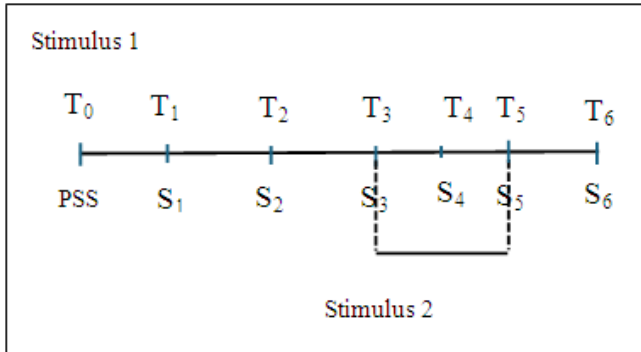


Figure 4. Continued activation of negative stimulus until  $T_6$

$(S_6 - S_0)$  is the accumulated stress between time points  $T_0$  and  $T_6$ , while  $(S_5 - S_0)$  is the accumulated stress between time points  $T_0$  and  $T_5$ .

$$S_6 - S_0 = \alpha_1 \cdot PI_1 \cdot (T_3 - T_0) + [\alpha_1 \cdot PI_1 + \alpha_2 \cdot PI_2] \cdot (T_5 - T_3) + \alpha_1 \cdot PI_1 \cdot (T_6 - T_5) \quad (26)$$

$$S_5 - S_0 = \alpha_1 \cdot PI_1 \cdot (T_3 - T_0) + [\alpha_1 \cdot PI_1 + \alpha_2 \cdot PI_2] \cdot (T_5 - T_3) \quad (27)$$

$$S_6 - S_0 = S_5 - S_0 + \alpha_1 \cdot PI_1 \cdot (T_6 - T_5) \quad (28)$$

Given  $(S_6 - S_0) - (S_5 - S_0) = \alpha_1 \cdot PI_1 \cdot (T_6 - T_5)$ , where  $(T_6 - T_5)$  and  $\alpha_1$  are positive and  $PI_1$  is negative, it follows that  $(S_6 - S_0) - (S_5 - S_0) < 0$ , or equivalently  $(S_6 - S_0) < (S_5 - S_0)$ .

It follows that the stress accumulated from  $T_0$  to  $T_6$  intensifies negatively, resulting in higher stress levels when the negative stimulus  $PI_1$  remains active while the positive stimulus ends.

Case 2: The positive stimulus remains active until  $T_6$ , while the negative stimulus ends at  $T_5$  (e.g. Figure 5).

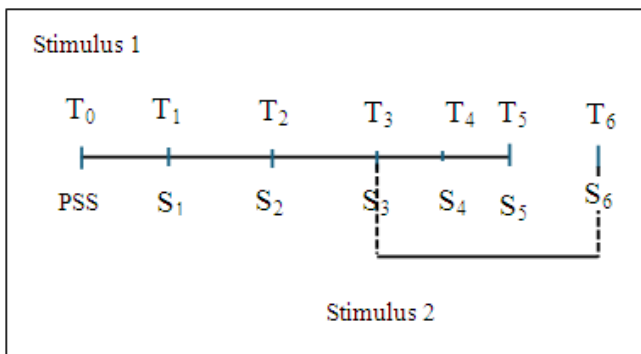


Figure 5. Continued activation of positive stimulus until  $T_6$

$(S_6 - S_0)$  is the stress accumulated between time points  $T_0$  and  $T_6$ , while  $(S_5 - S_0)$  is the stress accumulated between time points  $T_0$  and  $T_5$ .

$$S_6 - S_0 = \alpha_1 \cdot PI_1 \cdot (T_3 - T_0) + [\alpha_1 \cdot PI_1 + \alpha_2 \cdot PI_2] \cdot (T_5 - T_3) + \alpha_2 \cdot PI_2 \cdot (T_6 - T_5) \quad (29)$$

$$S_5 - S_0 = \alpha_1 \cdot PI_1 \cdot (T_3 - T_0) + [\alpha_1 \cdot PI_1 + \alpha_2 \cdot PI_2] \cdot (T_5 - T_3) \quad (30)$$

$$S_6 - S_0 = S_5 - S_0 + \alpha_2 \cdot PI_2 \cdot (T_6 - T_5) \quad (31)$$

Given  $(S_6 - S_0) - (S_5 - S_0) = \alpha_2 \cdot PI_2 \cdot (T_6 - T_5)$ , where  $(T_6 - T_5)$  and  $\alpha_2$  are positive and  $PI_2$  is positive, it follows that  $(S_6 - S_0) - (S_5 - S_0) > 0$ , or equivalently  $(S_6 - S_0) > (S_5 - S_0)$ .

From  $T_0$  to  $T_6$ , the accumulated stress diminishes, reflecting lower stress levels, when the positive stimulus continues while the negative stimulus ends.

These equation-predicted outcomes are consistent with previous findings. For instance, Matalka reported a reduction in cortisol levels following the cessation of the stressor [27].

6.4.5. The Impact of Stimulus Deactivation on Stress Accumulation

Referring to the situation illustrated in Figure 5, and assuming that the individual is exposed solely to a negative stimulus, **I** will demonstrate that after the stimulus is deactivated at  $T_5$ , the individual's sense of stress will gradually decrease over time.

Demonstrating this using only KTIRI-Stress accumulation (SAC) equation (20) is not possible, since  $SAC(T_0, T_6) = SAC(T_0, T_5) = \alpha_1 \cdot PI_1 \cdot (T_5 - T_0)$ , due to  $T_6 - T_5 = 0$ . Therefore, **I** apply the concept of stress power introduced above; see heading "6.3. The Concept of Stress Power and its Utility".

According to equation (22), the stress powers  $SP_1$  and  $SP_2$ , corresponding to intervals  $[T_0, T_5]$  and  $[T_0, T_6]$ , are given by:

$$SP_1 = SAC(T_0, T_5) / (T_5 - T_0) = \alpha_1 \cdot PI_1 \cdot (T_5 - T_0) / (T_5 - T_0) = \alpha_1 \cdot PI_1 \quad (32)$$

$$SP_2 = SAC(T_0, T_6) / (T_6 - T_0) = \alpha_1 \cdot PI_1 \cdot (T_5 - T_0) / (T_6 - T_0) \quad (33)$$

Since  $(T_5 - T_0) / (T_6 - T_0) < 1$ , it follows that  $SP_1 < SP_2$ .

Thus, the stress power increases in value-reflecting a reduction in experienced stress if the negative stimulus ends after  $T_5$ . Likewise, in the case of a positive stimulus, a decrease in stress power indicates a decline in the mental comfort once the stimulus ends.

These outcomes are consistent with previous studies. Martinez et al. reported that sympathetic nervous system activity, through which the stress response is expressed, ceases following the end of a stressor [28]. Similarly, it was noted that glucocorticoids levels, which are released into the bloodstream in response to stressor, return to baseline when the stressor ceases [29].

If the individual were exposed to a lower intensity of the same negative stimulus, denoted as  $PI_2$ , where  $PI_2 > PI_1$  in magnitude, the resulting stress power,  $SP_3$ , would be expressed as  $SP_3 = \alpha_2 \cdot PI_2 \cdot (T_5 - T_0) / (T_6 - T_0)$ . Since  $PI_2 > PI_1$  and their respective effects satisfy  $(\alpha_2 \cdot PI_2 > \alpha_1 \cdot PI_1)$  it follows that  $\alpha_2 \cdot PI_2 \cdot (T_5 - T_0) / (T_6 - T_0) > \alpha_1 \cdot PI_1 \cdot (T_5 - T_0) / (T_6 - T_0)$ . Thus,  $SP_3 > SP_2$ . Therefore,  $SP_3 > SP_2 > SP_1$ .

This leads to the conclusion that a less intense negative stimulus results in a more rapid decline in stress levels. In other words, lower stress leads to faster recovery once the negative stimulus is removed. Conversely, higher stress leads to slower

recovery after the stimulus ends.

#### 6.4.6. Effects of Ending a Negative Stimulus and Triggering a Positive Stimulus on Stress Accumulation

Continuing from the previous reasoning where negative stimulus 1 ends at  $T_5$ , resulting in  $SP1 < SP2$ , let us now consider a scenario in which a positive stimulus ( $PI_2$ ) is triggered at  $T_5$ . The stress accumulation between  $T_0$  and  $T_6$ , denoted SAC ( $T_0, T_6$ ), is given by:

$$SAC(T_0, T_6) = \alpha_1 \cdot PI_1 \cdot (T_5 - T_0) + \alpha_2 \cdot PI_2 \cdot (T_6 - T_5) \quad (34)$$

Since  $PI_2$  is positive, SAC ( $T_0, T_6$ ) is greater than  $\alpha_1 \cdot PI_1 \cdot (T_5 - T_0)$ . The resulting stress power denoted SP4 is then defined as:

$$SP4 = \alpha_1 \cdot PI_1 \cdot (T_5 - T_0) / (T_6 - T_0) + \alpha_2 \cdot PI_2 \cdot (T_6 - T_5) / (T_6 - T_0) \quad (35)$$

It follows that  $SP1 < SP2 < SP4$ .

Thus, the onset of a positive stimulus after the negative stimulus ( $PI_1$ ) ends leads to a more rapid decrease in stress power, indicating a steeper decline in stress levels compared to the scenario in which only the negative stimulus ( $PI_1$ ) ended.

#### 6.4.7. Combination of Positive and Negative Stimuli

Referring to the situation illustrated in Figure 4, where an individual is exposed simultaneously to two stimuli with respective perceived intensities  $PI_1$  and  $PI_2$  during the period [ $T_3, T_5$ ], the resulting stress accumulation is given by:

$$S_5 - S_3 = [\alpha_1 \cdot PI_1 + \alpha_2 \cdot PI_2] \cdot (T_5 - T_3) \quad (36)$$

The interaction between the two stimuli originates, according to the equation (36) above, from the combined effect of both contributing factors: the sum ( $\alpha_1 \cdot PI_1 + \alpha_2 \cdot PI_2$ ) and the shared exposure period [ $T_3, T_5$ ].

Suppose  $PI_1$  is positive and  $PI_2$  is negative, with the time interval [ $T_3, T_5$ ] held constant. If  $PI_2$  becomes more negative or less negative, while  $PI_1$  remains unchanged, then the value of the sum ( $\alpha_1 \cdot PI_1 + \alpha_2 \cdot PI_2$ ) decreases (becomes more negative) or increases, respectively. For example, an individual who hears a non-habituated noise while simultaneously engaging in a relaxation activity (a positive stimulus) of constant level will experience more or less stress depending on whether the perceived noise intensity increases or decreases, respectively.

Likewise, the value of the sum increases or decreases if  $PI_2$  remains constant, while  $PI_1$  increases (becomes more positive) or decreases, respectively. For example, if a subject hears a noise of constant perceived intensity, they will feel less or more stressed depending on whether they hear it during a party (positive stimulus) or alone, respectively.

The period [ $T_3, T_5$ ] also affects stress accumulation for an individual. Assuming  $PI_1$  and  $PI_2$  remain constant, if the duration of this period increases or decreases, the total effect of  $PI_1$  and  $PI_2$  experienced during the period will increase or decrease.

However, since  $PI_2$  is negative and  $PI_1$  is positive-meaning that the sum ( $\alpha_1 \cdot PI_1 + \alpha_2 \cdot PI_2$ ) acts like a subtraction-the

subject will remain more or less stressed depending on whether  $PI_1$  is initially less than or greater than the absolute value of  $PI_2$ , respectively. For instance, suppose an individual is simultaneously engaged in relaxation activity and exposed to noise whose perceived intensity does not disturb them, indicating that the perceived intensity of the relaxation is greater than that of the noise. The individual will remain less stressed during the period [ $T_3, T_5$ ], because the stress accumulation ( $S_5 - S_3$ )-see Equation (36)- will remain positive. Another example illustrating the dominant effect of a positive stimulus with greater intensity compared to a negative one is laughter. People may remain calm-or even feel relaxed-when exchanging jokes while engaging in physically tiring work.

This aligns with prior research indicating that laughter elevates serotonin in the human brain, thereby promoting more effective stress regulation and improving cognitive functions such as learning and information processing. [Poole et al., 2005 as cited in Rossi, 2015] [30] [31]. Similarly, increased serotonin has been shown to lower cortisol levels, which can impair immune system over the long term [32].

Based on the Ktiri-Stress Accumulation Equation, applied to the case where positive and negative stimuli interact, and supported by the cited research, I can describe an individual as not stressed if they are predominantly exposed to positive stimuli whose overall effect outweighs that of negative stimuli. This leads to the conclusion that, at a minimum, a subject must be surrounded by predominately-positive stimuli. Conversely, they will be considered stressed if they are exposed primarily to negative stimuli whose cumulative impact surpasses that of the positive ones.

#### 6.4.8. A Comparison between Single-Stressor Repetition and Multi-Stressor Exposure

If, for example, an individual is simultaneously exposed to three stressors with respective perceived intensities  $PI_1$ ,  $PI_2$  and  $PI_3$  during the time interval [ $T_0, T$ ], their stress accumulation is expressed as follows:

$$SAC = S_T - S_{T_0} = [\alpha_1 \cdot PI_1 + \alpha_2 \cdot PI_2 + \alpha_3 \cdot PI_3] \cdot (T - T_0) \quad (37)$$

It follows that,

$$\alpha_1 \cdot PI_1 \cdot (T - T_0) = SAC - [\alpha_2 \cdot PI_2 + \alpha_3 \cdot PI_3] \cdot (T - T_0) \quad (38)$$

If, instead of being exposed to three stressors, the same individual were exposed to only one stressor  $PI_1$  during the period [ $T_0, T_1$ ], with  $T_1 > T$ , the stress accumulation, denoted SAC1, would be as follows:

$$SAC1 = S_{T_1} - S_{T_0} = \alpha_1 \cdot PI_1 \cdot (T_1 - T_0) \quad (39)$$

Let us divide the interval [ $T_0, T_1$ ] into two subintervals: [ $T_0, T$ ] and [ $T, T_1$ ]. Comparing SAC and SAC1 and referring to equation (38), we have:

$$SAC1 = \alpha_1 \cdot PI_1 \cdot (T - T_0) + \alpha_1 \cdot PI_1 \cdot (T_1 - T) \quad (40)$$

$$SAC1 = SAC - [\alpha_2 \cdot PI_2 + \alpha_3 \cdot PI_3] \cdot (T - T_0) + \alpha_1 \cdot PI_1 \cdot (T_1 - T) \quad (41)$$

$$SAC1 - SAC = -[\alpha_2 \cdot PI_2 + \alpha_3 \cdot PI_3] \cdot (T - T_0) + \alpha_1 \cdot PI_1 \cdot (T_1 - T) \quad (42)$$

where  $[\alpha_2.PI_2 + \alpha_3.PI_3].(T - T_0)$  represents the effect of multiple stressors (in this case, two stressors:  $PI_2$  and  $PI_3$ ) active during the period  $[T_0, T]$ .

Assuming the interval  $[T_0, T]$  is constant, and since  $PI_2$  and  $PI_3$  are negative, the term  $(-[\alpha_2.PI_2 + \alpha_3.PI_3].(T - T_0))$  becomes positive constant. Equation (42) can be written as follows:

$$SAC1 - SAC = \text{positive constant} + \alpha_1.PI_1.(T_1 - T) \quad (43)$$

Thus, if the number of multiple stressors – or if their perceived intensities- are high enough to make the value of the positive constant greater than  $\alpha_1.PI_1.(T_1 - T)$ , and assuming that  $T_1$  is constant, the difference  $(SAC1 - SAC)$  will be positive – or equivalently,  $SAC1 > SAC$ . This implies that the stress accumulation due to multiple stressors (SAC) is more negative than that resulting from a single stressor (SAC1). In other words, the stress effect of multiple stressors is greater than that of a single stressor.

In contrast, suppose  $T_1$  increases to a value that makes the difference  $(SAC1 - SAC)$  negative. This means that the negative value of  $\alpha_1.PI_1.(T_1 - T)$  dominates the positive constant. This implies that the stress accumulation due to the single stressor (SAC1), which remains active for a longer period, becomes more negative than that resulting from multiple stressors.

I conclude that an individual experiences higher stress levels when subjected to a single continuous stressor for a prolonged period, compared to encountering multiple stressors over a brief period.

The outcomes presented above, as predicted by the Ktiri Stress Accumulation Equation, are consistent with findings reported in numerous previous studies, both early and recent.

In a very recent study, McDonnell and Gracia reported that exposure to multiple stressors or to a repeated ongoing stressor adversely affects mental health [33]. In comparing the impact of multiple versus single stressors, Malykhin et al. emphasized that it is the level of chronic stress-not daily hassles or perceived stress-that most strongly predicts general distress, depression, and anxiety [34]. Likewise, a frequently cited study found that static, ongoing stressors have a more harmful impact on health and well-being than temporary stressors [35].

## 6.5. The Conceptual Utility of the KTIRI-Stress Accumulation Equation

In general, over a given time interval  $[T_0, T]$ - such as during in everyday life-an individual may be exposed to a variety of both positive and negative stimuli. At the conclusion of this interval, the individual's perceived level of stress depends on their initial stress state at  $T_0$  (PSS) and the stress accumulated from stimuli converted into stress-related sensations (see heading "6.3. The Concept of Stress Power and its Utility), as described by the KTIRI-Stress and KTIRI-Stress accumulation equations.

For example, extending the duration of daily relaxation sessions or increasing exposure to positive stimuli can significantly reduce an individual's level of accumulated stress throughout the day, helping them end the day with a lower stress level.

Accordingly, the KTIRI-Stress and KTIRI-Stress accumulation equations, along with the concept of KTIRI-Stress power, provide a robust framework for modeling stress dynamics. Together, they offer a valuable methodological basis for developing a diagnostic tool to assess an individual's stress state and investigate its underlying causes.

## 7. Diagnosing an Individual's Stress

Numerous studies have been conducted to develop scales aimed at assessing an individual's stress level. These research-based scales typically consist of items presented in the form of questions. The subjective responses provided by the individual, using a likert scale (e.g., 'strongly agree', 'strongly disagree') [36], make it possible to evaluate their stress levels. The resulting stress level corresponds to a score obtained by summing the values assigned to each response.

Among the validated stress scales are:

- The perceived stress scale, based on the transactional model of stress [2], was developed in 1983 [37];
- The Perceived occupational stress scale [38].

Unlike traditional stress scales, I aim in this study, using the KTIRI-Stress and KTIRI-Stress accumulation equations, to present the features of a prototype representing a new-generation of stress diagnostic tool.

It is not a scale in the proper sense, but the purpose of administering it to an individual is to identify the number and types of stimuli they are exposed to in their daily or weekly life, including whether these stimuli are positive, negative, or both. In addition, this instrument is dynamic, with the number of items adapting to the individual being assessed.

### 7.1. Presentation of the Prototype

The new tool I propose, called the KTIRI- Stimuli Diagnostic Tool, first version (KTIRI-SDT V.1), is presented in tabular form, as shown in Table 2. It contains a series of questions designed to identify the stimuli to which an individual is frequently or regularly exposed in life.

I propose two variations of this tool: KTIRI-DSDT and KTIRI-WSDT. In the first, KTIRI-Daily Stimuli Diagnostic Tool, I identify the stimuli to which the individual is exposed in everyday life. In the second variation, KTIRI-Weekly Stimuli Diagnostic Tool, the questions focus on experiences throughout the week, acknowledging that some stimuli are periodic and only appear on specific weekdays.

For each item (stimulus), I present its type (positive or negative), its duration in minutes, the individual's perceived effect (PE), see heading "2.3. The Actual and Perceived Intensity of a Stimulus and their Respective Effects" and the accumulated stress, which is given by  $SAC = PE \cdot \Delta t$  (see equation (21)). The type (positive versus negative) is indicated because the stimulus can be perceived differently by different individuals. The perceived effect PE is assessed using a 6-point likert scale with the following response options: -3= Very stressful, -2=Stressful, -1=Slightly stressful, +1=Slightly relaxing, +2=Relaxing", and +3=Very relaxing.

**Table 2.** KTIRI-Stimuli Diagnostic Tool V.1

N°	Stimulus	Type	Time In MN	Perceived effect PE	SAC=PE. Δt
				VS or S or SS or SR or R or VR	
0	Awake-up (PSS)	N or P		PE <sub>0</sub>	
1	Stimulus 1	N or P	Δt <sub>1</sub>	PE <sub>1</sub>	PE <sub>1</sub> .Δt <sub>1</sub>
...	.....	.....	.....	.....	.....
i	Stimulus i	N or P	Δt <sub>i</sub>	PE <sub>i</sub>	PE <sub>i</sub> .Δt <sub>i</sub>
i+1	Stimulus i+1	N or P	Δt <sub>i+1</sub>	PE <sub>i+1</sub>	PE <sub>i+1</sub> .Δt <sub>i+1</sub>
n	Stimulus n	N or P	Δt <sub>n</sub>	PE <sub>n</sub>	PE <sub>n</sub> .Δt <sub>n</sub>

**Table 3.** The KTIRI-Stimuli Diagnostic Outcomes V.1

Indicator	Number N	Total duration In MN TD	Total perceived effect TPE	Total stress accumulation TSAC
Positive				
Negative				
PSS				
APWP				
RPWP				
PS/RPWP				
NS/RPWP				
TSAC				
SP=TSAC/ APWP				

A response option, in fact, reflects the perceived effect of a stimulus represented by the product  $\alpha \cdot PI$  (see heading “3.1. Integration of Individual Sensitivity to the Stimulus (Parameter  $\alpha$ )). For example, when a subject reports that a stimulus is “very stressful”, this suggests that the perceived effect results from the individual’s sensitivity ( $\alpha$ ) and the perceived intensity (PI), which is, in turn, shaped by the coping strategy employed.

I do not include a “neutral” option in the response scale. If a subject does not perceive the stimulus as negative, the response is interpreted as reflecting a slight positive effect (e.g., “Slightly relaxing” or “relaxing”). This approach is intentional and theoretically justified.

First, in Section 6.4.5, “The Impact of Stimulus Deactivation on Stress Accumulation”, I demonstrate that once a negative stimulus ends, there is reduction in experienced stress—almost as if a fictional, slight positive stimulus is triggered by the cessation of the negative one. Second, in my theoretical study of the T-TTS [1], particularly in Section 5.1, “No Stimuli Means Positive Stimuli”, I proposed that “the fact that a person is doing nothing but having rest could be evaluated as positive stimulus which could reduce their stress” (p. 105).

The first item in the tool’s table (see Table 2), which I consider crucial and reflective of the core principles of the Tri-Transactional Theory of Stress, is the AWAKE-UP item. It reflects the level of stress individuals experience upon waking and serve as indicator of their initial baseline stress state (PSS) at the start of each day.

After administering the “KTIRI-SDT”, KTIRI-DSDT or

KTIRI - WSDT, tool to the subject, some indicators are measured and reported in a separate table (Table 3) titled KTIRI-Stimuli Diagnostic Outcomes (KTIRI-SDO V.1: KTIRI-DSDO v.1 or KTIRI-WSDO v.1). These indicators, which summarize the individual’s stress condition, include:

- the number of positive and negative Stimuli ( $N$ );
- the active time of positive and negative stimuli in minutes (total duration:  $TD$ );
- the total perceived effect of positive and negative Stimuli ( $TPE$ );
- the total stress accumulation of positive and negative stimuli ( $TSAC$ ).

Additional indicators are also included, namely:

- the state of stress at *AWAKE-UP* (PSS);
- the Absolute Post-Wakeup period (APWP), which represents the period between waking-up and going to bed;
- the relative Post-Wakeup period (RPWP), which represents the total duration of all stimuli experienced between waking-up and going to bed. RPWP is always greater than or equal to APWP ( $RPWP \geq APWP$ );
- the percentage of the active time of positive stimuli relative to the relative post-wake period ( $PS/RPWP$ );
- the percentage of the active time of negative stimuli relative to the relative post-wake period ( $NS/RPWP$ );
- the total stress accumulation due to positive and negative stimuli ( $TSAC$ ); and
- the stress power (SP), calculated by dividing the total

stress accumulation (TSAC) by the absolute Post-Wakeup period (APWP).

This information helps determine to what extent the individual leads a stressful or restful life. Accordingly, tailored advice will be provided, either to eliminate or reduce certain negative stimuli, or to introduce positive stimuli or increase their intensity.

The new-generation of stress diagnostic tool, the KTIRI-Stimuli Diagnostic Tool (KTIRI-SDT), **I am** developing will be very effective and beneficial in helping stressed individuals more aware of how they lead their daily or weekly lives.

## 7.2. Case Study

### 7.2.1. Case Study Presentation

In this section, **I** take the scenario presented in the illustrative case of stress accumulation above-see heading “6.1. A Case Illustrating Stress Accumulation”-and add some other stimuli, using it as a case study to which **I** will apply the KTIRI-SDT tool. Assuming the man’s daily routine remains consistent throughout the week, **I** will use the Daily Stimuli Diagnostic Tool Variation (KTIRI-DSDT).

The two additional stimuli are as follows: after he leaves his friend, he usually goes home and engages in a slightly

stressful verbal conflict with his wife for about one hour. Then, he turns on the TV and watches a film, which he considers a slight recovery period, until 11:30 p.m., at which point he goes to bed.

The man who has begun to suffer from sleep deprivation and some psychosomatic symptoms, consults a healthcare professional. The latter administers a conventional stress scale to him.

The score he obtains is high. This index is important, as it provides an initial indication of his stress level. However, this is insufficient, and the therapist wants to understand how the man leads his daily or weekly life in relation to the environmental stimuli he is exposed to. Suppose this man wakes up every day at 9 a.m., already in a state described as stressful (-2) (see heading 7.1. Presentation of the Prototype) and goes to bed at 11.30 p.m. The KTIRI-Stimuli Diagnostic Tool results for this case are presented in Table 4. Stimulus 4 (worrying message) (see heading “6.1. A Case Illustrating Stress Accumulation”) is not included in the table, as it is not a stimulus that occurs every day.

Since the case is fictional, the responses related to the man’s perceived effects (PE) are only approximate estimates.

In Table 5, I present the results of the KTIRI-Daily Stimuli Diagnostic Outcomes (KTIRI-DSDO) for this man.

**Table 4.** The Man’s Ktiri-DSDT v.1 Results

N°	Stimulus	Type	Time In MN	Perceived effect PE	SAC =PE. Δt
0	Awake-up (PSS)	N		-2 (S)	
1	Transport to work	N	35	-2 (S)	-70
2	Thinking negatively about his job	N	35	-2 (S)	-70
3	Boring work	N	480	-1 (SS)	-480
4	Return from work	N	40	-2 (S)	-80
5	2 hours sleeping	P	120	+3 (VR)	+360
6	Pleasant chatting with his friend at the café	P	90	+2 (R)	+180
7	Verbal conflict with his wife	N	60	-1 (SS)	-60
8	Watching film	P	45	+1 (SR)	+45

**Table 5.** The Man’s Ktiri-DSDO v.1 Results

Indicator	Number N	Total duration In MN TD	Total perceived effect TPE	Total stress accumulation TSAC
Positive	3	255	+6	+585
Negative	5	650	-8	-760
PSS			-2	
APWP			870 MN	
RPWP			905 MN	
PS/RPWP			28,18 %	
NS/RPWP			71,82 %	
TSAC			-175 (175 units of daily stress received)	
SP= TSAC/ APWP			-0,20 (0,20 units of daily stress received per minute)	

### 7.2.2. Case Study Interpretation

The results of the KTIRI-DSDO (Table 5) show that the number of negative stimuli is not very high compared to the positive ones (5 versus 3). Their respective total perceived effects are also not significantly different (-8 versus +6). However, the total active period of negative stimuli, relative to the total exposure time to both negative and positive stimuli (RPWP), significantly exceeds that of the positive ones (71,82% versus 28,18%). This indicates that the duration of stimulus exposure plays a key role in determining the resulting perceived effect (“See heading “A Comparison between Single-Stressor Repetition and Multi-Stressor Exposure”).

The man’s stress levels apparently stem from his perceived boring job and the type of transport he uses on a daily basis. He should therefore focus on resolving these two issues before thinking about increasing the number of positive stimuli (such as sleep, coffee, etc.).

## 8. Implications

The theoretical revision of the Tri-Transactional Theory of Stress (Tri-TTS) and the development of a prototype for a new-generation stress diagnostic tool offer significant benefits.

First, the revision of the stress equation will enable future researchers to test the validity of the Tri-TTS on other population groups without the need to use the previously confusing variable, stimulus objective intensity ST.

Second, using developed equations, both theorists and practitioners can predict the phenomenon of stress accumulation and its relation to stimuli.

Finally, the new-generation stress diagnostic tool, in both of its variations (KTIRI-DSDT, KTIRI-WSDT), derived from the newly revised KTIRI-Stress Accumulation Equation, will enable health professionals, particularly psychologists, to explore the underlining causes of stress experienced by individuals.

## 9. Conclusions

The aim of the present theoretical study was to advance the Tri-Transactional theory of stress by refining the KTIRI-Stress equation. I eliminated the confusion caused by the stimulus objective intensity variable (ST), which had previously been used in the empirical study [3] and could lead to ambiguity in interpretation in future research. In the revised equation, I introduced the concepts of stimulus perceived intensity (PI) and individual sensitivity ( $\alpha$ ). As a result, I developed a simplified model of stress accumulation allowing us to enhance our understanding of the phenomenon, with its interpretation aligned with the findings of previous studies. As part of the theory revision, another key concept was introduced, referred to as the Stress power (SP) concept. First, SP enables us to determine the rate at which stimuli are converted into sensations of stress. Second, it allows us to explain certain stress accumulation phenomena that the

corresponding equation fails to account for.

The refined equation also led to the development of a new-generation stress diagnostic tool based on the KTIRI-Stress and KTIRI-Stress accumulation equations. This tool, called the KTIRI-Stimuli Diagnostic Tool first version (KTIRI-SDT V.1), is presented in two variations: the KTIRI-Daily Stimuli Diagnostic Tool (KTIRI-DSDT) and the KTIRI-Weekly Stimuli Diagnostic Tool (KTIRI-WSDT).

The revision the Tri-Transactional theory of stress- through its stress and stress accumulation equations, along with the introduction of new parameters and concepts, is significantly beneficial for future research in the field of stress.

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