A second-order adaptive temporal-causal network model for age and gender differences in evolving choice of emotion regulation strategies

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ABSTRACT

Emotion being an essential part of one’s life, its regulation is of utmost importance. The choice of strategies that one employs for regulating their emotions, varies at various stages of their lives and with contexts. Similarly, gender also has an influence on the choice of emotion regulation strategies. This paper presents a second-order adaptive network model for this phenomenon where the choice of strategies varies with age and gender in an adaptive manner. Simulation results for both the genders (male and female) have been provided where for both the genders, choice of emotion regulation strategies changes as age increases. The second-order adaptive network model presented here extends a non-adaptive network model previously introduced at ICCCI’19.

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Introduction

Emotion regulation (ER) is a process where people try to alter the flow of their spontaneous emotions in some direction (Koole, 2009). Emotions play a key role in one’s social life. On one hand, its regulation is very important to cope up with daily life routines in a better way as emotional problems can occur anytime with varying intensities during a day. On the other hand, failure or inefficient emotion regulation can have various negative psychological consequences. So, it’s not only important for better mental and physical health to regulate emotions (Koole, 2009), it’s also important to regulate negative emotions to avoid vital psychological consequences (Aldao & Nolen-Hoeksema, 2010; Gross, 2013). There are various ER strategies (Gross, 1998), the efficacy of which is dependent on the situation (Aldao, Sheppes, & Gross, 2015).

Apart from the contextual employment of different strategies and their level of efficacy for different individuals, various studies from social sciences have also reported differences in choice of emotion regulation strategies in terms of age and gender. According to findings from (Gross & John, 2003; Spaapen, Waters, Brummer, Stopa, & Bucks, 2014) men tend to use suppression in younger age in comparison to women who tend to use reappraisal in young age. In contrast, with an increase in age, a shift takes place: when men grow older they turn to reappraisal from suppression while women move from reappraisal to suppression as their
age increases (Masumoto, Taishi, & Shiozaki, 2016). On the basis of these findings from psychology and an already developed non-adaptive model for age and gender differences in choice of emotion regulation strategies (Gao, Liu, & Ullah, 2019), this work extends the non-adaptive network model in (Gao et al., 2019) to a second-order adaptive network model (Treur, 2016, 2020). The newly introduced adaptive network model gives an in-depth overview of the choices of ER strategies over time. This approach from (Treur, 2016, 2020) has been used because emotion and its regulation involve a cyclic and adaptive temporal process that adaptive temporal-casual network modelling particularly addresses. Some work has already been done on emotion regulation using this modelling approach; for instance, (Abro, Klein, Manzoor, Tabatabaei, & Treur, 2015; Abro, Manzoor, Tabatabaei, & Treur, 2015) present models for the role of ER strategies on mood and its consequences. (Manzoor, Abro, & Treur, 2017) considers the sensitivity level in the choice of ER strategies. Similarly, (Ullah, Treur, & Koole, 2018) presents a model for contextual emotion regulation. Most close to the model presented here is the model presented in (Ullah & Treur, 2020) which also is adaptive and demonstrates the role of age in choice of emotion regulation strategies but does not consider the role of gender in choice of emotion regulation strategies. The complexity and novelty of the current model lies in the multi-order adaptive approach along with considering both the age and gender.

Background

The role of gender and age differences in the expression of emotions (Brody & Hall, 2008; Grills, 2002) and its regulation has been investigated and proved by various studies from social science and psychology. For instance, taking expression of emotions into account to explain the differences, contrary to men, women are said to express their sadness and suppress their anger (Timmers, Fischer, & Manstead, 1998). This trend in differences in men and women in terms of emotions also applies to their choices of emotion regulation strategies. In general, men are said to use more suppression as compared to women (Gross & John, 2003). Further narrowing down the spectrum of men to younger men, (John & Gross, 2004) is of the view that young men more often turn to suppression in comparison to young women. Exploring the second half of the subject in question, (Spaapen et al., 2014) state that women more frequently use reappraisal as compared to men. The reason for these differences in choices of emotion regulation strategies as per findings of (Gross & John, 2003) is the parental role as they expect and rather motivate their sons to have more emotional control as compared to their daughters (Underwood, Coie, & Herbsman, 1992) and therefore boys are expected to inhibit emotional expressions to a greater extent than girls. It is also discussed that women tend to appraise stressors more severely than men do, so they report more use of positive reappraisal (Underwood et al., 1992).

Contrary to what strategies both the genders use when they are young, their choices of strategies change as they grow older. This phenomenon has been reported by (Nolen-Hoeksema & Aldao, 2011), who classifies ages 20–35, 45–55 and 65–75 as young, middle and adult, respectively and state that women turn to suppression as an emotion regulation strategy as they grow older. On the other hand, men are said to turn to more frequent use of reappraisal with age and the reason for this choice is considered to be their awareness of the positive aspects of life with age (Masumoto et al., 2016).

It’s worth mentioning here that cognitive reappraisal and expression suppression are the most studied strategies for such differences because they both work in an opposite way to
each other. The former refers to a form of re-interpretation by changing one’s belief about something, i.e. that can be from negative to positive or vice versa (Buhle et al., 2014). It is an antecedent-focused strategy that tries to handle the negative emotions at the very beginning of its generation or in other words before its actual generation. Therefore it’s said to be efficient in down-regulating the negative emotions, and reducing all the experiential and behavioural components of negative emotion (Gross & John, 2003). Contrary to reappraisal, suppression tries to inhibit one’s emotional expressive behaviour while emotionally aroused (Gross & Levenson, 1993). It’s considered to be a response-focused strategy, as it addresses states that occur later in the causal path of emotion generation; although it should be effective in cutting the behavioural expression of the negative emotion, the expression of positive emotion may also be decreased (Gross & John, 2003).

**Conceptual representation of the model**

The proposed computational model is explained in this section. This model is based on the Network-Oriented Modelling approach based on temporal-casual networks (Treur, 2020), briefly explained below; see also (Treur, 2016, 2019). A network model is defined by its network structure characteristics *connectivity, aggregation* and *timing*, for which a conceptual representation is given in Table 1, followed by the network’s numerical representation that can be derived from the conceptual representation.

The Network-Oriented Modelling approach provides different ways to specify how causal impacts are aggregated on a specific state by using certain combination functions. For this purpose, not only a library of standard combination functions is available, own-defined functions can also be added.

**Table 1.** Conceptual and numerical representations of a temporal-casual network model.

| Concept | Conceptual representation | Explanation |
|---------|---------------------------|-------------|
| States and connections | $X, Y, X \rightarrow Y$ | Describes the nodes and links of a network structure (e.g. in graphical or matrix form) |
| Connection weight | $\omega_{X,Y}$ | The connection weight $\omega_{X,Y}$ usually in $[-1,1]$ represents the strength of the causal impact of state $X$ on state $Y$ through connection $X \rightarrow Y$. |
| Aggregating multiple impacts on a state | $c_i(\cdot)$ | For each state $Y$ a combination function $c_i(\cdot)$ is chosen to combine the causal impacts of other states on state $Y$. |
| Timing of the effect of causal impact | $\eta_Y$ | For each state $Y$ a speed factor $\eta_Y \geq 0$ is used to represent how fast a state is changing upon causal impact |
| Concept | Numerical representation | Explanation |
| State values over time $t$ | $Y(t)$ | At each time point $t$ each state $Y$ in the model has a real number value, usually in $[0,1]$. |
| Single causal impact | $\text{impact}_{X,Y}(t) = \omega_{X,Y}X(t)$ | At state $X$ with a connection to state $Y$ has impact on $Y$, using connection weight $\omega_{X,Y}$. |
| Aggregating multiple causal impacts | $\text{aggimpact}_Y(t) = c_i(\text{impact}_{X_1,Y}(t), \ldots, \text{impact}_{X_n,Y}(t)) = c_i(\omega_{X_1,Y}X_1(t), \ldots, \omega_{X_n,Y}X_n(t))$ | The aggregated causal impact of multiple states $X_i$ on $Y$ at $t$, is determined using combination function $c_i(\cdot)$. |
| Timing of the causal effect | $Y(t + \Delta t) = Y(t) + \eta_Y[\text{aggimpact}_Y(t) - Y(t)]\Delta t$ | The causal impact on $Y$ is exerted over time gradually, using speed factor $\eta_Y$. Here the $X_i$ are all states with outgoing connections to state $Y$. |
Using the developed dedicated modelling environment (Treur, 2020, Chapter 9), a conceptual representation of a temporal-causal model is automatically transformed into a numerical representation according to the lower part of Table 1, resulting in the following difference and differential equations:

\[ Y(t + \Delta t) = Y(t) + \eta_Y[c_Y(\omega_{X1}, \gamma X1(t), \ldots, \omega_{Xk}, \gamma Xk(t)) - Y(t)]\Delta t \]

or

\[ \frac{dY(t)}{dt} = \eta_Y[c_Y(\omega_{X1}, \gamma X1(t), \ldots, \omega_{Xk}, \gamma Xk(t)) - Y(t)] \]

The second-order adaptive network model introduced here has three levels, in 3D each graphically depicted in one (horizontal) plane. The lower plane contains the base network, whereas the middle and upper plane represent the adaptation principles applied. A graphical conceptual representation of the base network (lower plane) is provided in Figure 1, followed by its nomenclature in Table 2.

The base network in Figure 1 shows how the choice of ER strategies depends on age and gender. All connections, except the connections in red carry positive weights.

The world state \( w_s \) refers to a stimulus \( s \) in the world which triggers some emotions resulting in a causal pathway for some response action \( a \) through states \( s_{ss}, s_{srs}, p_{sa}, e_{sa} \). The belief state \( bs \) refers to a negative interpretation of the stimulus; it leads to a causal pathway for a negative feeling based on body state \( b \), through states \( s_{ss}, s_{srs}, f_{sb}, p_{sb}, e_{sb} \). The preparation \( p_{sb} \) for body state \( b \) and execution \( e_{sb} \) for body state \( b \)

![Figure 1. Conceptual representation of the base level of the network model.](image)

| State | Explanation | Level |
|-------|-------------|-------|
| \( X_1 \) | \( w_s \) | World state for stimulus \( s \) | Base Level |
| \( X_2 \) | \( ss \) | Sensor state for stimulus \( s \) |
| \( X_3 \) | \( s_{rs} \) | Sensory representation state for stimulus \( s \) |
| \( X_4 \) | \( p_{sa} \) | Preparation state for action \( a \) |
| \( X_5 \) | \( e_{sa} \) | Execution state for action \( a \) |
| \( X_6 \) | \( ss_b \) | Sensor state for body state \( b \) |
| \( X_7 \) | \( s_{srs_b} \) | Sensory representation state for body state \( b \) |
| \( X_8 \) | \( f_{sb} \) | Feeling state for body state \( b \) |
| \( X_9 \) | \( p_{sb} \) | Preparation state for body state \( b \) |
| \( X_{10} \) | \( e_{sb} \) | Execution state for body state \( b \) |
| \( X_{11} \) | \( bs_- \) | Negative belief state about the stimulus \( s \) |
| \( X_{12} \) | \( bs_+ \) | Positive belief state about the stimulus \( s \) |
| \( X_{13} \) | \( c_{rs\text{reapp}} \) | Control state for reappraisal |
| \( X_{14} \) | \( c_{rs\text{sup}} \) | Control state for suppression |
| \( X_{15} \) | \( ss_m \) | Sensor state of being male |
| \( X_{16} \) | \( s_{rs_m} \) | Sensory representation state of being male |
| \( X_{17} \) | \( ss_f \) | Sensor state of being female |
| \( X_{18} \) | \( s_{rs_f} \) | Sensory representation state of being female |
provides feedback and enhances the emotional response to stimulus s through an as-if-body loop (Damasio, 2010).

The choice of using a specific strategy depends on the gender and age. Gender is differentiated by ss_f and ss_m, i.e. the sensor state of being female and the sensor state of being male, respectively. These states have associated external influences from parents and other people (Gross & John, 2003; Masumoto et al., 2016). The effects of these influences differ for younger age or older age which makes the two different genders go for different emotion regulation strategies of different ages.

The control state of reappraisal cs_reapp suppresses belief state bs, thus changing the negative interpretation of the stimulus, which subsequently increases the positive interpretation of the stimulus modelled by belief state bs+. Therefore, the feeling state fs also decreases. In contrast, the control state for suppression cs_supr suppresses the expression of emotion while the negative belief still remains high. As a result, the person may feel even higher intensity of the negative emotions but he keeps suppressing his body state.

**Higher order adaptation**

In contrast to the non-adaptive network model in (Gao et al., 2019), in the model introduced here higher-order adaptation is addressed (Treur, 2020). Figure 2 shows the first and second reification levels of the model along with the base model already shown in Figure 1. The nomenclature for the first and second reification levels in Figure 2 is given in Table 3.

The 2nd and 3rd level of the model in Figure 2 play an important role in the evolution of the base network over time. The first-order adaptation at the first reification level (i.e. the W-states) represents an adaptation principle called Hebbian learning, which can be temporally positive as well as negative. The adaptation of the choice of a specific strategy over time depends on two factors, i.e. age and gender. The adaptation process takes place by
the dynamics of the $W$-states which represent the Hebbian learning. They each represent a specific connection weight for the base model, and their dynamics can make these weights increase or decrease over time. Table 4 below defines the choice of strategies for male and female over age as found in literature.

The third level of the model called second reification level, is used to control the speed and persistence of the first reification level, i.e. of the $W$-states. The $H$-states are used as reified states representing the speed factor of the respective first-order reified $W$-states. So, the $H$-states’ dynamics make the learning speed adaptive over time. Similarly, $M$-states represent the persistence factor of their respective $W$-states in the first-order adaptation. The $M$-states’ dynamics make the persistence of their respective $W$-states adaptive over time. In this way, more levels can be added depending upon the phenomenon being modelled.

This model demonstrates how the choice of using specific emotion regulation strategies varies between male and female and, more specifically, how it alters over age. Initially, males typically use suppression and then this turns to reappraisal. In contrast, female typically use reappraisal and then turn to suppression. The dynamics of this phenomenon is modelled by the dynamics of the $W$-states. For instance, in case of male, initially $W_{srsf,csreapp}$ is stronger but with the passage of time and decrease of the external influences mentioned in literature, $W_{srsf,csreapp}$ starts getting weaker. In contrast, $W_{srsf,m,csreapp}$ starts lower and is getting stronger over time and finally, reappraisal becomes the most used emotion regulation strategy for males, as mentioned in the literature.

To conceptually specify a multi-level network model in a matrix format, the notion of role matrices has been introduced (Treur, 2020). In each role matrix, each node $X_i$ has a row. Each role matrix addresses a specific type of characteristic of the network and the row of a given node $X_i$ defines the incoming causal impact to it from that characteristic. In the role matrices given in Boxes 1 and 2, for connectivity, base matrix $mb$ specifies the states with incoming connections to state $X_i$. The green cells in connection weight matrix $mcw$ for connectivity indicate the non-adaptive (static) network characteristics. In contrast, the red cells that have state numbers, i.e. $X_{ji}$ indicate adaptive characteristics

| State | Explanation | Level |
|-------|-------------|-------|
| $X_{15}$ | $W_{srsf,csreapp}$ | Reified representation state for connection weight $W_{srsf,csreapp}$ | First Reification Level |
| $X_{16}$ | $W_{srsf,csreapp}$ | Reified representation state for connection weight $W_{srsf,csreapp}$ | Second Reification Level |
| $X_{17}$ | $W_{srsf,csreapp}$ | Reified representation state for connection weight $W_{srsf,csreapp}$ | |
| $X_{18}$ | $W_{srsf,csreapp}$ | Reified representation state for connection weight $W_{srsf,csreapp}$ | |
| $X_{19}$ | $W_{srsf,csreapp}$ | Reified representation state for persistence factor $\mu$ for $W_{srsf,csreapp}$ | |
| $X_{20}$ | $W_{srsf,csreapp}$ | Reified representation state for speed factor $\eta$ for $W_{srsf,csreapp}$ | |
| $X_{21}$ | $W_{srsf,csreapp}$ | Reified representation state for speed factor $\eta$ for $W_{srsf,csreapp}$ | |
| $X_{22}$ | $W_{srsf,csreapp}$ | Reified representation state for speed factor $\eta$ for $W_{srsf,csreapp}$ | |
| $X_{23}$ | $W_{srsf,csreapp}$ | Reified representation state for speed factor $\eta$ for $W_{srsf,csreapp}$ | |
| $X_{24}$ | $W_{srsf,csreapp}$ | Reified representation state for speed factor $\eta$ for $W_{srsf,csreapp}$ | |
| $X_{25}$ | $W_{srsf,csreapp}$ | Reified representation state for speed factor $\eta$ for $W_{srsf,csreapp}$ | |
| $X_{26}$ | $W_{srsf,csreapp}$ | Reified representation state for speed factor $\eta$ for $W_{srsf,csreapp}$ | |

Table 3. Nomenclature of the 2nd and 3rd layers states of the model.

| Age       | Gender | Choice of Strategies | Respective W states |
|-----------|--------|----------------------|---------------------|
| Young     | Male   | Suppression           | $W_{srsf,csreapp}$  |
| Older     | Female | Reappraisal           | $W_{srsf,csreapp}$  |
|           | Male   | Reappraisal           | $W_{srsf,csreapp}$  |
|           | Female | Suppression           | $W_{srsf,csreapp}$  |

Table 4. Choice of emotion regulation strategies vs age.
of the network wherein the value of $X_j$ changes over time exhibiting evolution of that specific characteristic of the network over time.

### Box 1. Role matrices for connectivity.

| mb | Connectivity: | mcw | Connectivity: |
|----|---------------|-----|---------------|
|    | Base connectivity | 1  | 1  |
| $X_1$ | $w_1$ | $X_1$ | $w_1$ | 1  |
| $X_2$ | $ss_1$ | $X_2$ | $ss_2$ | 1  |
| $X_3$ | $srs_3$ | $X_3$ | $srs_3$ | 1  |
| $X_4$ | $ps_4$ | $X_4$ | $ps_4$ | 0.3 |
| $X_5$ | $es_5$ | $X_5$ | $es_5$ | 0.3 |
| $X_6$ | $ss_6$ | $X_6$ | $ss_6$ | 1  |
| $X_7$ | $srs_7$ | $X_7$ | $srs_7$ | 0.4 |
| $X_8$ | $fs_8$ | $X_8$ | $fs_8$ | 1  |
| $X_9$ | $ps_9$ | $X_9$ | $ps_9$ | 0.2 |
| $X_{10}$ | $es_{10}$ | $X_{10}$ | $es_{10}$ | 1  |
| $X_{11}$ | $bs_{11}$ | $X_{11}$ | $bs_{11}$ | 0.6 |
| $X_{12}$ | $bs_{12}$ | $X_{12}$ | $bs_{12}$ | 0.4 |
| $X_{13}$ | $cseapp$ | $X_{13}$ | $cseapp$ | 0.4 |
| $X_{14}$ | $cspup$ | $X_{14}$ | $cspup$ | 0.4 |
| $X_{15}$ | $w_{stry,cseapp}$ | $X_{15}$ | $w_{stry,cseapp}$ | 1  |
| $X_{16}$ | $w_{stry,cspup}$ | $X_{16}$ | $w_{stry,cspup}$ | 1  |
| $X_{17}$ | $w_{strm,cseapp}$ | $X_{17}$ | $w_{strm,cseapp}$ | 1  |
| $X_{18}$ | $w_{strm,cspup}$ | $X_{18}$ | $w_{strm,cspup}$ | 1  |
| $X_{19}$ | $m_{wstry,cseapp}$ | $X_{19}$ | $m_{wstry,cseapp}$ | 0.5 |
| $X_{20}$ | $m_{wstry,cspup}$ | $X_{20}$ | $m_{wstry,cspup}$ | 0.5 |
| $X_{21}$ | $h_{wstry,cseapp}$ | $X_{21}$ | $h_{wstry,cseapp}$ | 0.5 |
| $X_{22}$ | $h_{wstry,cspup}$ | $X_{22}$ | $h_{wstry,cspup}$ | 0.5 |
| $X_{23}$ | $w_{strm,cseapp}$ | $X_{23}$ | $w_{strm,cseapp}$ | 0.8 |
| $X_{24}$ | $h_{wstrm,cseapp}$ | $X_{24}$ | $h_{wstrm,cseapp}$ | 1  |
| $X_{25}$ | $h_{wstrm,cspup}$ | $X_{25}$ | $h_{wstrm,cspup}$ | 0.6 |
| $X_{26}$ | $m_{wstrm,cseapp}$ | $X_{26}$ | $m_{wstrm,cseapp}$ | 0.5 |
| $X_{27}$ | $ss_m$ | $X_{27}$ | $ss_m$ | 1  |
| $X_{28}$ | $srs_m$ | $X_{28}$ | $srs_m$ | 1  |
| $X_{29}$ | $ss_f$ | $X_{29}$ | $ss_f$ | 1  |
| $X_{30}$ | $srs_f$ | $X_{30}$ | $srs_f$ | 1  |
Box 1 i.e. matrix mb gives insight into all the incoming connections to any state. It’s worth noting here that all the connections in mb are either upward connections or connections at the same level, that means that there’s no downward connection in the mb. The downward connections from higher layers to lower layers are those connections which effectuate adaptivity. The downward connections are represented in the other role matrices, for example, here in mcw by stating the proper state name with its number (reference) in the red cells. For example, by putting X₁₇ in the fourth column for X₁₃, it is indicated that state X₁₇ plays the role of connection weight for the fourth incoming connection of X₁₃. So, role matrix mcw represents all adaptive (in red cells) and nonadaptive (in green cells) connection weights of the incoming connections to state Xᵢ. The range of these values (connection weights) is usually between 0 and 1, but for supressing links they can be between 0 and −1, Moreover, the state numbers Xᵢ in
red cells in \textbf{mcw} are those states at the higher level which control the adaptivity of the incoming adaptive connection to that specific state.

Similarly, for the \textit{aggregation} characteristics, \textbf{Box 2} represents role matrix \textbf{mcfw} which indicates which combination function out of the library of 36 combination functions has been used. Moreover, role matrix \textbf{mcpf} gives (in the green cells) the values for nonadapative combination function parameters steepness $\sigma$ and threshold $\tau$. In the red cells, role matrix \textbf{mcpf} also indicates the $\mathbf{M}$-states which are responsible for controlling the adaptive persistence parameters $\mu$. A persistence factor is used to indicate how long or short the learned connection retains its value. Moreover, in \textbf{Box 2}, the \textit{timing} role matrix \textbf{ms} shows the non-adaptive speed factor values in the green cells. For the adaptive timing characteristics, in the red cells state numbers are indicated for the $\mathbf{H}$-states (states that represent the speed of the adaptive connections) that control the indicated speed factor.

**Scenarios and simulation results**

This section shows simulation results for the adaptive network model presented above. The parameters used to obtain these results are given in \textbf{Boxes 1} and 2. They have been chosen in such a manner that the graphs exhibit the same pattern as found by various studies from psychology. Based on the computational model and literature above, here’s an example scenario of the model:

When a person finds it difficult to make it to an important appointment, a negative emotion arises. For regulation of such a negative emotion, young men are expected to turn to suppression as they are taught to do so (Gross & John, 2003; Underwood et al., 1992), while older men tend to reappraise, because they look more at the positive side as they grow older (Masumoto et al., 2016). Young women are taught to reappraise in such situations so, they prefer reappraisal, while older women may use suppression more often which may reflect the uncontrollable nature of the stress they face. (Blanchard-Fields, 2007)

In the simulation results below, \textbf{Figure 3} and \textbf{Figure 6} represent the choices of strategies used by males and females in childhood and older age, respectively. \textbf{Figure 4} and \textbf{Figure 7} shows the first-order reified states and \textbf{Figure 5} and \textbf{Figure 8} gives insight into the second-order reified representation for males and females over time, respectively.

\textbf{Figure 3} demonstrates the choice of emotion regulation strategies of men over time with increase in age. The graph depicts findings from the literature that initially males are supposed to suppress their emotions which can be seen in the graph wherein initially suppression $cs_{\text{sup}}$ gets activated to suppress negative emotions. At the same time, with increase in age, reappraisal $cs_{\text{reapp}}$ also starts to increase slowly and gradually. It’s worth noting here that the negative belief and intensity of negative emotions is still high when the person is suppressing his negative emotions which is why suppression of emotions is said to be psychologically a maladaptive emotion regulation strategy in most situations. In contrast, as the person gets older and turns to cognitive reappraisal, he starts changing his negative belief about the stimulus which, in turn, also decrease his intensity of negative emotions. Therefore, reappraisal is said to be an adaptive strategy for emotion regulation in most of the cases (In general, the specific context defines the adaptivity or maladaptivity of emotion regulation strategies).
Figure 3. Choice of male’s emotion regulation strategies over time (base model).

Figure 4. First-order reified representation states for males over time.

Figure 4 gives the first-order reified representation states for males over time. These states are represented by $W_{SRSM,CSUP}$ and $W_{SRSM,CSEAPP}$ for male. States $W_{SRSM,CSUP}$ represents the adaptive connection from $SRSM$ to $CS\text{_SUP}$ while $W_{SRSM,CSEAPP}$ represents the adaptive connection from $SRSM$ to $CS\text{_EAPP}$. In the figure it can be seen that initially $W_{SRSM,CSUP}$ is high at
the start of the simulation but decreases as time increases. This represents the childhood of a male where they are supposed to suppress their emotions. In contrast, as time passes by, $W_{Srsm,creapp}$ starts to increase which represents the transition from one strategy to another, i.e. from suppression to reappraisal over time. How fast or slow this adaptation is taking place, is controlled by the respective $H$- and $M$-states in the second-order reified level explained below.

Figure 5 shows the $H$- and $M$-states for the respective $W$-states; they control the speed and persistence factors of the $W$-states which represent the adaptation taking place for an adaptive connection in the base network. In the graph above, $M_{W_{Srsm,creapp}}$ and $H_{W_{Srsm,creapp}}$ are responsible for controlling the persistence and speed factor of $W_{Srsm,creapp}$, respectively. It should be noted that the curves representing these states are decreasing over time and the reason has been explained that initially male are supposed to suppress their emotions but as they grow older, they turn to reappraisal because of the various factors explained. Moving on to the curves for $M_{W_{Srsm,creapp}}$ and $H_{W_{Srsm,creapp}}$, these two states are responsible for controlling the persistence and speed factor of $W_{Srsm,creapp}$, respectively. All these three states are increasing over time, representing that as the person grows older, his choice of strategy changes from suppression to reappraisal. How fast or slow it changes, or in which part of one’s life this change is actually taking place is represented by the characteristics for these second-order states. Given real data about a person’s life, it’s possible to set the appropriate values for these characteristics in order to get the exact pattern.

Similarly, Figures 6, 7 and 8 represent the dynamics of female’s choice of emotion regulation strategies over time. Figure 6 above represents the states in the base network, the adaptation of which is controlled from the upper levels, i.e. the first-order and second-order reification states. In the figure, it can be seen that initially when the negative
stimulus $s_{rs}$ triggers the negative belief $b_s$ and negative feeling state for body $f_{sb}$, the control state for reappraisal $c_{reapp}$ gets activated. This represents the early age of a girl’s life where she’s taught to reappraise contrary to boys who are taught to suppress their negative emotions. The control state for reappraisal $c_{reapp}$ changes negative belief $b_s$.

**Figure 6.** Choice of female’s emotion regulation strategies over time (base model).

**Figure 7.** First-order reified representation state for female over time.
of the person so the positive belief $b_{s_+}$ of the person gets higher as visible in the graph. Now as the girl gets older, the choice of emotion regulation strategy changes. She turns to use suppression rather at later stages of her life. Therefore, it can be seen in the figure that the control state for suppression $c_{sup}$ increases slowly and gradually until it becomes the only priority of the person for her emotion regulation. The emotion regulation pattern becomes a very clear suppression strategy. As suppression only suppresses emotions wherein the intensity of negative emotion is still high and the negative belief is also there, the same is visible in the figure as well.

Figure 7 shows the first-order reified representation state over time for female; these states are $W_{srsf,csreapp}$ and $W_{srsf,cssup}$. Here $W_{srsf,csreapp}$ represents the adaptive connection from $srsf$ to $csreapp$ and $W_{srsf,cssup}$ represents the adaptive connection from $srsf$ to $cssup$. These connection gets weaker or stronger as the girl gets older as per literature as she gets out from one kind of influence but enters into other kinds of influences. These influences either force her to use reappraisal (initially) or use of suppression (in the later state of her life). So, in the graph, it can be seen that initially $W_{srsf,csreapp}$ is higher but continuously decreasing over time which, on one hand, shows the usage of reappraisal in the initial stage of a female’s life but, on the other hand, it shows decrease in its usage over time. Similarly, $W_{srsf,cssup}$ is initially very low but it slowly and gradually keeps increasing over time, which exhibits the transition from reappraisal to suppression in a later stage of female’s life. The other dynamics like speed factor and persistence factor for this first-order reified states is handled from the second-order reified states explained below.

Figure 8 gives insight into the second-order reified representation states for female over time. The states involved are $H_{W_{srsf,csreapp}}$, $H_{W_{srsf,cssup}}$, $M_{W_{srsf,csreapp}}$ and $M_{W_{srsf,cssup}}$ which controls speed and persistence factors respectively. Here $H_{W_{srsf,csreapp}}$ and $M_{W_{srsf,csreapp}}$ are responsible
for the speed and persistence factors of $W_{sstf,cs reap}$ in the first-order reified representation layer and $H_{W_{sstf,cs reap}}$ and $M_{W_{sstf,cs reap}}$ are responsible for handling of the speed and persistence factors of $W_{sstf,cs reap}$ in the first-order reified level, respectively. Moving on to further explanation of the curves, as already mentioned that females initially use reappraisal in their childhood but as they get rid of their parents’ influence, they come under some other influences so they turn to using suppression in the later stage of their lives. Therefore, in the simulation results above, it can be seen that the speed and persistence factors involved in reappraisal decreases over time. In contrast, the speed and persistence factors involved in suppression are increasing over time. This pattern demonstrates the transition of a female from reappraisal to suppression with increasing age, which is exactly as found by scholars in their research carried out on gender and age differences in choice of emotion regulation strategies from psychology.

**Conclusion**

The network model introduced here extends the network model (Gao et al., 2019) in two ways. First, as mentioned in the possible future work section of (Gao et al., 2019), adaptivity has been added to the model where the connections either get stronger or weaker over time as in real life. So, in contrast to (Gao et al., 2019), the simulation results now represent an entire life episode in terms of emotion regulation strategies. In real life, some connections will get stronger due to some factors at one stage of life and other connection will get weaker due to some other reasons and this process keeps taking place throughout one’s life. A second extension added here is the second-order adaptive network-oriented modelling approach described in (Treur, 2020). This new network model has first- and second-order reified representation states which control the dynamics of the adaptive connections in the base model. This makes it easy to handle the speed and persistence factors of the adaptive connections in a Network-Oriented Modelling manner which makes it more realistic and can easily get validated.

**Disclosure statement**

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