Computational Model for Changing Sedentary Behavior through Cognitive Beliefs and Introspective Body-feelings

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Abstract: Sedentary behavior has emerged as a serious risk factor for numerous health outcomes. However, little work has been done to approach the problem through social-cognitive theories. In this study, a network model has been proposed for sedentary behavior intervention based on Influential determinants from major social-cognitive theories i.e., theory of planned behavior and health-belief model. Accounting for these determinants means that we are influencing behavior with a peripheral route, for which we included the somatic markers as a body-feelings in the model. An effective behavior change techniques from literature are used to affect these determinants to change the sedentary behavior. The model has been mathematically represented and simulated using a network-oriented modelling technique for an office employee.

1 INTRODUCTION

Sitting behaviour is characterized by any waking behavior with an energy expenditure of ≤1.5 metabolic equivalents (METs). You can be sedentary at work, at school, at home, when travelling or during leisure time while watching television, studying or working at a desk or computer. A person can do enough physical activity to meet the guidelines and still be considered sedentary if he/she spends a large amount of his/her time sitting or lying down (Weggemans et al., 2018). Moreover, low level or moderate-to-vigorous level physical activity is not the same as being sedentary for example, I cycle to the office every day (which is Dutch culture) and then sit at a computer for around 6-7 hours, so it is possible for being highly sedentary and highly active at the same time. Prolonged sitting has several adverse health outcomes including increased risk of type 2 diabetes, higher risk of premature death and death from cardiovascular disease (Australian Government guidelines for sedentary behavior, 2019) (Weggemans et al., 2018).

A number of theories and models from social and behavioral sciences can assist us to make sense of behaviour and the world around us. More specifically for sedentary behavior, a number of ecological model/theories are proposed, but they are seldomly used. In a recent review (Huang, Benford, & Blake, 2019), 19 out of 63 digital interventions for sedentary behavior are based on some theoretical grounds (among them the theory of planned behavior is used for 5 times and social cognitive theory for 4 times). Whereas from digital technological prospective the sedentary behavior intervention mostly uses mobile apps and wearable sensors (Taj, Klein, & van Halteren, 2019). Sedentary behavior interventions usually follow ecological models that define multifaceted determinants of the problem, including individual, social, and environmental policy level (Owen et al., 2011).

A shortcoming of the ecological model is that they fail to acknowledge the role of psycho-social variables in explaining sedentary behavior (Prapavessis et al., 2015). On an individual level, different characteristic like beliefs, motivation or

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intention etc. can influence sedentary behavior. For understanding these types of determinants, socio-cognitive theories are the best options to be reached out (Sallis, Owen, & Fisher, 2015). Sedentary behavior in the workplace is high; 71–77% of working hours are being spent sedentary (Scherer, 2005). It requires minimal effort or conscious planning and is highly habitual. To change workplace sedentary behavior, we need to target these determinants using effective behavior change strategies, which will also be discussed later in the paper.

In this paper, we focus on a conceptual model that considers psycho-social determinants to reason about sedentary behavior and use different behavior change techniques to break a sedentary behavior.

The aims of this research includes: Identifying the key psycho-social determinants from different health cognitive theories for sedentary behaviour. Exploring the popular behavior change strategies/techniques from literature to target these determinants ans lastly, modeling the findings as a computational network model and simulating an office employee working scenario using the model.

In Section 2 of the paper, the background of the constructs from different theories are given and discusses the behavior change techniques (BCTs) that can be used to influence these determinants. In section 3, the conceptual and mathematical representation of network-oriented model is presented. Section 4 contains the scenario and the simulation results. The paper has been concluded in Section 5 with a brief insight into the future directions.

2 BACKGROUND

This section provides the background for the model we proposed. In the first part, theories and working of its determinants/parameters are discussed with linkage to sedentary behaviors. The second part of this section discusses different behaviour change techniques with its association to the determinants of the theories.

2.1 Socio-psychological Determinants

Most of the health cognitive theories describe possible relationships between the psycho-social factors and sedentary behavior, but theory of planned behavior (TPB) has been mostly used in this context (Prapavessis et al., 2015). According to TPB, an individual’s intention is the main determinant of actual sedentary time. The intermediate determinants of intention are attitude, subjective norms (SN), and perceived behavioral control (PBC). Attitude represents an individual’s evaluation of the perceived benefits and cost of sitting, SN reflects a belief about whether most people approve or disapprove an action, and PBC refers to individual’s perception of their ability to control the time they spend being sedentary (Prapavessis et al., 2015, Ajzen, 2005).

Health belief model (HBM) is the theory mostly used to identify the determinants which explain the likelihood of engaging in health-promoting behavior. Perceived outcomes and self-efficacy are the main constructs in HBM. Similarly, from Social Cognitive Theory (SCT), self-efficacy construct suggests a setting of realistic and measurable goals to ensure initial success and the outcome expectancies construct would suggest highlighting the benefits of reducing sedentary time e.g., reduced muscle stiffness etc. (Owen et al., 2011). The application of social cognitive theory for health behavior change has focused predominantly on increasing self-efficacy, for example, confidence in one’s own abilities (Bandura, 1998). The perceived self-efficacy is highly correlated with goal attainment, higher the self-efficacy, higher the goals people set for themselves (Bandura, 2004). There exists a fair amount of cross-sectional studies that correlate social cognitive constructs to workplace setting but the association between social-cognitive factors and sedentary behavior needs much more exploration (Hadgraft et al., 2017).

Among different theoretical models, most of the determinants are overlapping and most of the researcher overload their studies with the dictum that more is better (Bandura, 2004). The determinants discussed above are basically the internal cognitive beliefs of humans. We represented these determinants as positive and negative beliefs, for example, perceived benefit (HBM) and self-efficacy (HBM, TPB, SCT) are the positive beliefs about the action. Similarly, perceived severity and susceptibility to disease/behavior (HBM) are the negative beliefs about the outcomes. Moreover, subjective norms in TPB corresponds to expected social outcomes for a given behavior. Perceived behavioral control in TPB overlaps with perceived self-efficacy in SCT (Bandura, 2004).

2.2 Behavior Change Techniques

In any intervention, BCTs are an important active ingredient that may explain study variation in-effectiveness. Effective sedentary reduction intervention depends on understanding and reasoning about what works and why (Michie et al., 2013). A taxonomy is available which describes 93 discrete behaviour change techniques that can be used in interventions within any behavioural domain e.g. providing information on health consequences, setting goals, restructuring the physical environment. Behaviour change techniques represent the observable and irreducible intervention components that serve to perform one or more functions (Michie et al., 2013).

Developing intervention based on theories and models suggest using the available systematically verified BCTs to effectively target the determinants noted in the above section. For example, from SCT and TPB the use of self-efficacy construct suggests the use of goal-setting e.g. setting a walking goal to the corridor door after every 30 minutes of work, and self-monitoring e.g. maintains sitting time record book (Owen et al., 2011). BCT taxonomies are new and are seldom reported in digital behavior change interventions (Direito et al, 2016). It has been observed that only 10 out of potential 93 BCTs were present (mean of 2.42 BCTs were present in each app) (Dunn, 2017). Table 1 shows the description of each of the determinant with scale description, source theory/model, and some of the effective BCT to target these determinants, coded from recent BCTs taxonomy (Michie et al., 2013). The best resource available to find the linkage between BCT and the above-mentioned determinants (mechanism of action) is the human behaviour change project (https://www.humanbehaviourchange.org/). In one of the studies in this project, they published the triangulating evidence of links made by authors in published scientific studies and by expert consensus (https://theoryandtechniquetool.humanbehaviourchange.org/).

3 NETWORK-ORIENTED MODEL

Network-oriented temporal-causal network modelling approach (Treur, 2016) has been used for modelling the above concepts. The temporal dimension enables the modelling of cyclic causal relations with exact timing. The reason for representing it as a causal network lies in the fact that most of the determinants are subjective beliefs and they are causally linked like a network. There are two types of beliefs presented in the model, the positive and negative beliefs; self-efficacy and perceived benefit are presented as positive beliefs about the current sedentary behaviour and the perceived susceptibility and severity are negative beliefs about sedentary behaviour. The two types of actions i.e., sedentary behaviour (sitting) and non-sedentary behaviour (walk) are inversely influenced by these positive and negative beliefs.

The network-oriented models can be represented in two ways i.e., graphical representation and numerical representation. Fig. 1 shows the graphical representation of the proposed model. In section 3.1, the graphical representation is converted into a numerical or mathematical representation.

In the model, a person sedentary behavior is represented with the states i.e., preparation for action (ps_{a1}) and execution of action (es_{a1}). Whereas, the walking behavior is represented with states i.e., (ps_{a2}) and execution of action (es_{a2}). The determinants discussed in section 2 are represented by different states in the network for example, perceived susceptibility and severity are represented with state name $\text{srs}_{p.susptblty}$, $\text{srs}_{p.svrty}$ respectively. The scenario discussed in section 4, shows how perceived susceptibility and severity of the action affects the actions execution and how after the intervention, efficacy and perceived benefits increases.

This shift in beliefs is model used the Damasio's somatic marker hypothesis, i.e., introspective feelings. It plays a critical role in the ability to make fast, rational decisions in complex and uncertain situations (Damasio, 1998). The feeling actually serves a kind of monitoring and helps in choosing the best possible options for action. This feeling state is affected by predictive as-if body loop, which gives a sense of preview and valuing the action before it has actually been performed.

3.1 Mathematical Representation

A network-model illustrated in fig. 1 involves states that reflect actual world anomalies, and the arrows indicate the causal connection between the two entities. Important notions for each of the state and connection are as follow:

- **Connection($\omega_{X,Y}$):** represents the connection value between the states (x,y). The value represents the strength of causality and its value ranges between [-1, 1].

Speed Factor (η_Y): How fast the state value going to change with incoming causal impact.

Table 1: Determinants with scale description and coded behavior change techniques.

Determinant		Scale Description	BCT
Perceived Severity (HBM)	Negative beliefs	One's belief of how serious a condition and its consequences are E.g. How confident are you that long sitting can cause serious chronic illnesses.	BCT: 5.1. Information about health consequences BCT: 9.2. Pros and cons BCT: 10.1. Material incentive (behaviour) BCT: 10.10. Reward (outcome)
Perceived Susceptibility (HBM)	Negative beliefs	One's belief of the chances of getting a condition. E.g. How confident are you that your health will not be with long sitting.	BCT: 5.1. Information about health consequences BCT: 5.2 Salience of consequences
Social norms (SCT, TPB)		Perceived organization/social support for less sitting at work. E.g. My workplace environment has an open choice to stand or move more at work.	BCT: 6.3. Information about others' approval BCT: 6.2. Social comparison
Perceived Benefits (HBM)	Positive beliefs	One's belief in the benefit of the advised action to reduce the risk or seriousness of the impact E.g. How confident are you that small breaks after every 30 minutes will help me avoiding chronic disease.	4.1 Instruction on how to perform behavior — how, where, when 5.3 Information about social and environmental consequences.
Self-Efficacy (HBM, SCT, TPB)	Positive beliefs	Confidence in one's ability to act. Provide training, guidance, and positive reinforcement E.g. How confident would have been that you could have stood up during the meeting.	BCT: 1.2. Problem solving BCT: 8.7. Graded tasks BCT: 4.1. Instruction on how to perform behaviour BCT: 6.1. Demonstration of the behaviour

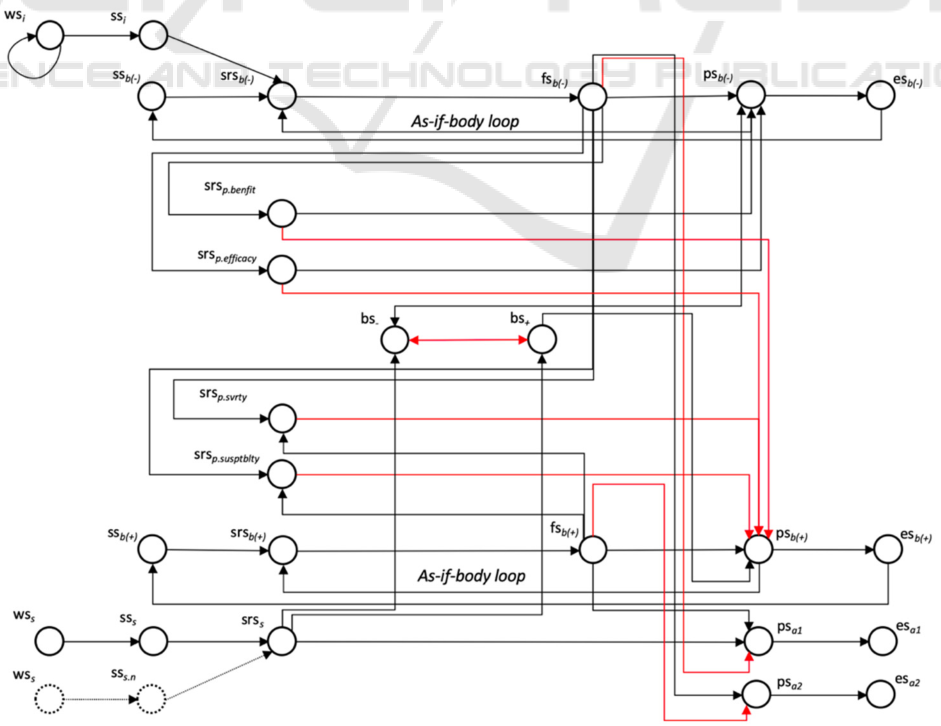

Figure 1: The network model for sedentary behavior change. The red lines show the negative connections and black lines are the positive connections.

- **Combination Function (c_Y(...)):** is used to combine the causal impact of multiple incoming states. This approach provides a library of currently 40 combination functions for the aggregation of multiple (incoming) causal impacts.

$$\text{Impact}_{X,Y} = \omega_{X,Y}\, X(t) \quad (1)$$

Total aggregated impact on state Y at time t combined by combination function.

$$\text{aggimpact}_Y(t) = c_Y(\text{impact}_{X1,Y}, \text{impact}_{X2,Y}, \text{impact}_{X3,Y}, \ldots)$$

$$= c_Y(\omega_{X1,Y} X_1(t), \omega_{X2,Y} X_2(t), \omega_{X3,Y} X3(t), \ldots) \quad (2)$$

The $\text{aggimpact}_Y(t)$ will have upward or downward effect at time point t, but how fast this change takes place depends on the speed factor η_Y,

$$\mathbf{Y(t+\Delta t) = Y(t) + \eta_Y\, [aggimpact_Y(t) - Y(t)]\, \Delta t} \quad (3)$$

The following difference (eq.4) and differential equation (eq.5) can be obtained for state Y:

$$\mathbf{Y(t+\Delta t) = Y(t) + \eta_Y\, [cY(\omega_{X1,Y}\, X1(t), \omega_{X2,Y}\, X2(t), \omega_{X3,Y}\, X3(t), \ldots) - Y(t)]\Delta t} \quad (4)$$

$$\mathbf{dY(t)/dt = \eta Y\, [c_Y(\omega_{X1,Y}\, X1(t), \omega_{X2,Y}\, X2(t), \omega_{X3,Y}\, X3(t), \ldots) - Y(t)]} \quad (5)$$

3.2 Parameters Formalization

The states represented in the model are cognitive states having continuous one-dimensional value e.g. sad vs happy. The causal connections shown by black and red arrow shows the positive and negative influence of one state on other, respectively. We have scaled all type of values in the range of [-1,1] and simulation time (t) is set for 200 steps.

The parameters required to define the network models are: initial value, connection value, combination function, and speed factor for each state. The initial value for each of the state are set according to the situation e.g., in simulation below for ws_s and ws_i have initial values of 1 and 0.11, respectively and rest of the state's initial value are set to 0. To combine the incoming effect on any state, a number of options available for choosing among the different combination function. In the proposed model, the identity and advanced logistic sum combination $\text{alogistic}_{\sigma,\tau}(\ldots)$ functions are used as the standard combination function. The parameters for combination functions (τ, σ)and speed of factors (η) of the states for the scenario (discussed below) are given in Table 3.

4 SCENARIO AND SIMULATION RESULTS

Consider an office situation where an employee, Mavrik works in front of a computer from 9 to 5. He is not aware of the severity and susceptibility of being sedentary and do not have the self-belief that he should overcome this behaviour. The organization started a campaign (intervention) for providing information to the employees about the negative consequences of sitting more than consecutives 30 minutes and offered them 10 minutes break after each 1 hour of work (reward). With this campaign, the employee starts realizing the severity and susceptibility of the prolonged sitting, which leads to an increase in his attitude towards taking a break after each hour. Now with the campaign, the employee starts perceiving the benefit of walking and his efficacy gets increased, so it reduces the sedentary behaviour. To simulate the above scenario, the connection values and the combination functions are described in the table 2 & 3.

The parameter values shown in these tables can be used to reproduce the results shown in fig. 2, 3 and 4 below. Moreover, only ws_s and ws_i have initial values of 1 and 0.11 respectively. States with zero values for τ and σ in table 3 suggest that Identity function has been used for these sates.

Fig 2 displays all the states of the model. It can be seen that initially the person's negative belief about his current sedentary behavior is almost zero. Which means, the perceived susceptibility and severity of his sedentary behaviour are also very low. Therefore, the person keeps sitting for long time in office.

In the second half of the fig. 2, it's observable that a shift takes place in the dynamics of the states. This shift is because of the intervention proposed for the person for breaking the continuity of his sedentary action. This intervention changes the person's belief by making him walk/move after certain amount of time.

Table 2: The connection values (ω) between the two states.

Connection	Weight	Connection	Weight	Connection	Weight
ω_{ws_s,ss_s}	1	$\omega_{ps_{b+},es_{b+}}$	0.8	$\omega_{ss_i,srs_{b-}}$	0.5
ω_{ss_s,srs_s}	1	ω_{esb_+,ssb_+}	0.75	$\omega_{ssb_-,srs_{b-}}$	0.5
$\omega_{srs_s,ps_{a1}}$	0.2	$\omega_{srs_{p.susptblty},ps_{b+}}$	-0.2	$\omega_{srs_{b-},fs_{b-}}$	0.8
ω_{srs_s,bs_-}	.4	$\omega_{srs_{p.svrty},ps_{b+}}$	-0.2	$\omega_{fs_{b-},ps_{a1}}$	-0.6
$\omega_{ps_{a1},es_{a1}}$	1	ω_{bs_-,bs_+}	-0.8	$\omega_{fs_{b-},ps_{a2}}$	0.8
$\omega_{ps_{a2},es_{a2}}$	1	$\omega_{bs_-,ps_{b-}}$	0.6	$\omega_{fs_{b-},srs_{p.susptblty}}$	0.4
$\omega_{ss_{b+},srs_{b+}}$	0.4	$\omega_{bs_+,ps_{b+}}$	1	$\omega_{fs_{b-},srs_{p.svrty}}$	0.45
$\omega_{srs_b,fs_{b+}}$	0.9	$\omega_{bs_+,ps_{b-}}$	-0.8	$\omega_{fs_{b-},srs_{p.efficacy}}$	0.48
$\omega_{fs_{b+},ps_{a1}}$	0.6	$\omega_{srs_{p.efficacy},ps_{b+}}$	-0.6	$\omega_{fs_{b-},srs_{p.benifit}}$	0.55
$\omega_{fs_{b+},ps_{a2}}$	-0.6	$\omega_{srs_{p.efficacy},ps_{b-}}$	0.3	$\omega_{fs_{b-},ps_{b-}}$	0.3
$\omega_{fs_{b+},ps_{b+}}$	1	$\omega_{srs_{p.benifit},ps_{b+}}$	-0.6	ω_{ps_{b-},bs_-}	1
$\omega_{fs_{b+},srs_{p.susptblty}}$	0.1	$\omega_{srs_{p.benifit},ps_{b-}}$	0.3	$\omega_{ps_{b-},srs_{b-}}$	0.5
$\omega_{fs_+,srs_{p.svrty}}$	0.1	ω_{ws_i,ws_i}	1	$\omega_{ps_{b-},es_{b-}}$	0.8
$\omega_{ps_{b+},srs_{b+}}$	0.3	ω_{ws_i,ss_i}	1	$\omega_{es_{b-},ss_{b-}}$	0.8

Table 3: The parameter of alogistic$_{\sigma,\tau}$ (…) combination function and speed factor for different states.

State	τ	σ	η	State	τ	σ	η
ws_s	0	0	0	$srs_{p.svrty}$	0.25	8	0.5
ss_s	0	0	1	bs_-	0.2	3	0.4
srs_s	0.4	8	0.2	bs_+	0.3	10	0.4
ps_{a1}	0	0	0.5	$srs_{p.efficacy}$	0.3	8	0.5
es_{a1}	0	0	0.5	$srs_{p.benefit}$	0.3	8	0.5
ps_{a2}	0	0	0.5	ws_i	0.2	8	0.02
es_{a2}	0	0	0.5	ss_i	0.2	8	0.02
ss_{b+}	0.35	8	0.4	$ss_{b\_}$	0.3	8	0.2
srs_{b+}	0.35	8	0.4	$srs_{b\_}$	0.3	8	0.1
fs_{b+}	0.35	8	0.4	$fs_{b\_}$	0.3	7	0.2
ps_{b+}	0.4	8	0.4	$ps_{b\_}$	0.28	7	0.1
esb_+	0.4	8	0.4	es_{b-}	0.3	8	0.1
$srs_{p.susptblty}$	0.25	8	0.5				

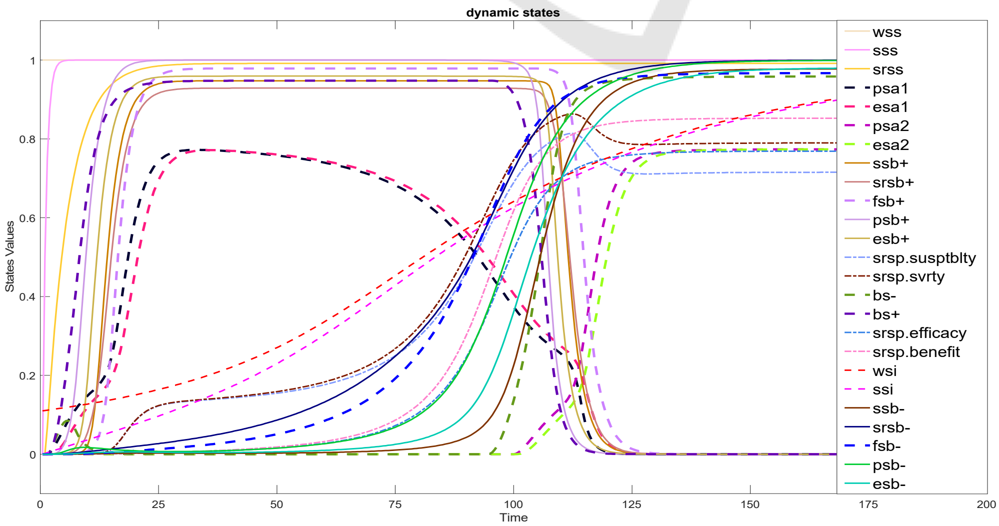

Figure 2: The simulation result of the model with the state values mentioned in table 2 & 3.

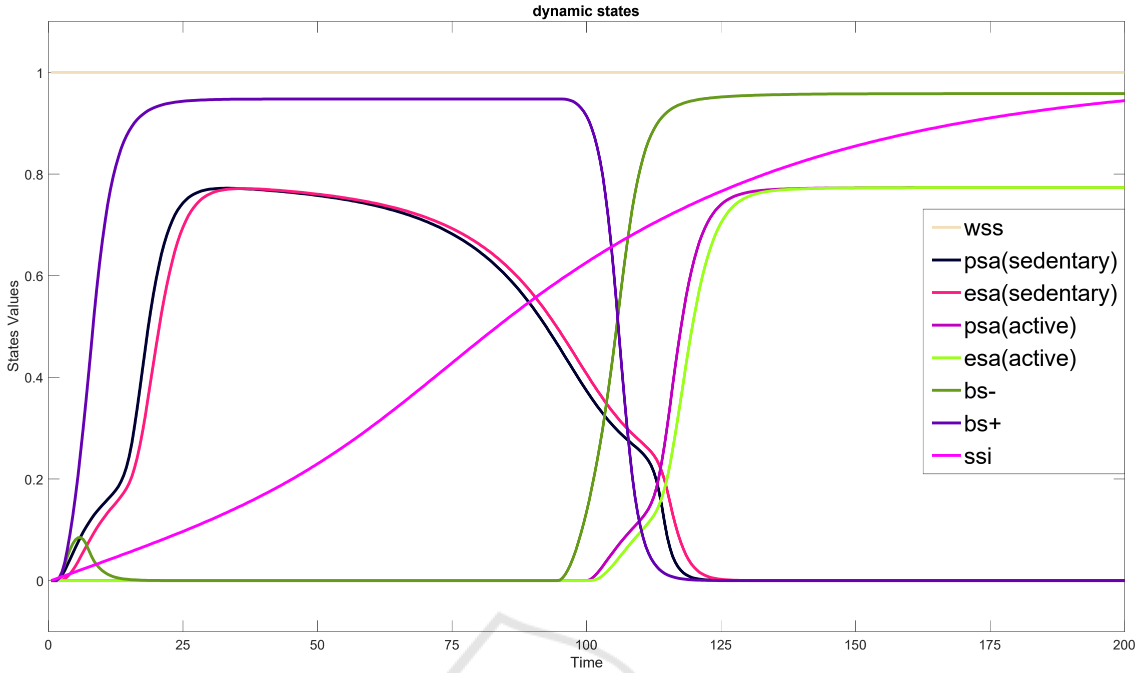

Figure 3: The sedentary behavior (esa(sedentary)) is high and the walking behavior (esa(active)) is low, but latter after with intervention effect, the sedentary behavior went down and walking behavior got high.

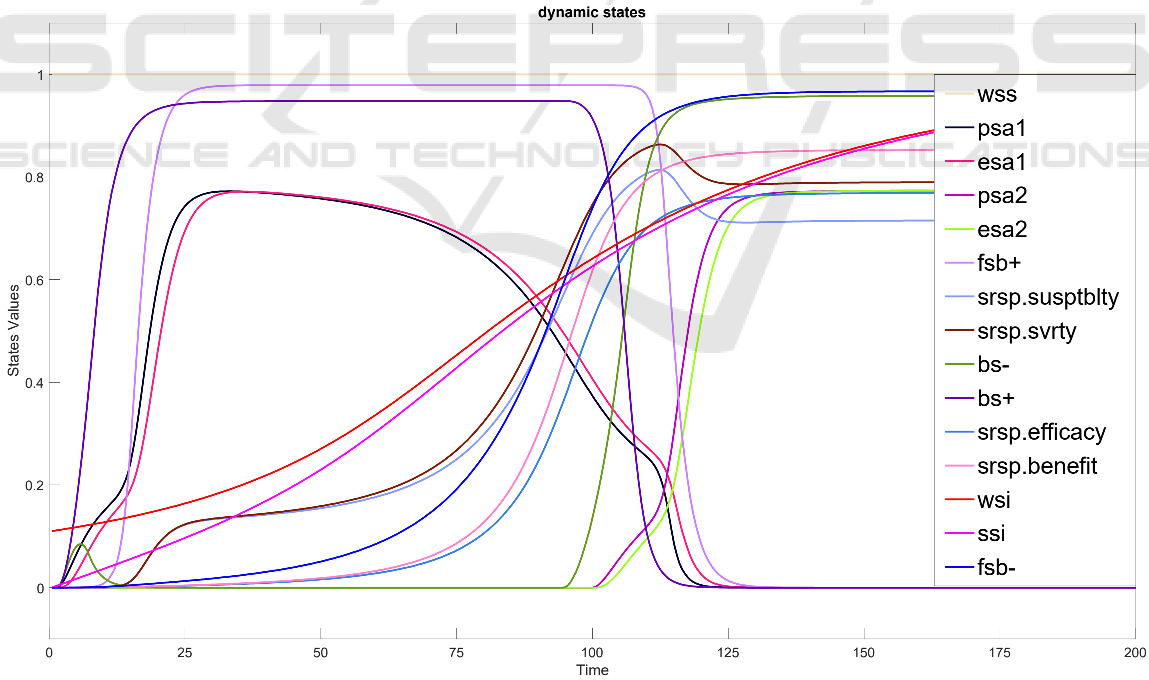

Figure 4: All the cognitive belief states. The susceptibility and severity were initially too low and after the intervention it gets high.

Fig. 3 shows that initially the person's negative belief (bs_-) about his sedentary behaviour is low and positive belief (bs_+) is high. Hence his sedentary action (ps_{a1},es_{a1}) are high. In fig. 4, when the intervention ws_i and ss_i gets activated to an enough level, which changes the person's belief, the perceived susceptibility $srs_{p.susptblty,}$ and severity $srs_{p.svrty}$ of the sedentary action get increased. Negative belief (bs-) increases and positive belief (bs+) decreases. As a result, the person's non-sedentary action i.e., preparation for action '2' ps_{a2} and execution of action '2' es_{a2} also increases while sedentary behaviour i.e., preparation for action '1' ps_{a1} and execution of action '1' es_{a1} decreases

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