# AN AGENT BASED SIMULATION OF THE DYNAMICS IN COGNITIVE DEPRESSOGENIC THOUGHT

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Abstract: Depression is a common mental disorder. Appropriate support from others can reduce the cognitive distortion that can be caused by subsequent depressions. To increase our understanding of this process, an agent model is presented in this paper in which the positive and negative effects of social support and its relation with cognitive thoughts are modelled. Simulations show the effect of social support on different personality types. A mathematical analysis of the stable situations in the model gives an additional explanation of extreme cases. Finally, a formal verification of expected relations between support, risk factors and depressive thoughts is performed on the simulation traces to check whether the simulations describe realistic processes.

## 1 INTRODUCTION

Cognitive vulnerability is one of the main concepts that play an important role to escalate the risk of relapse in affective disorder (depression). In a broader spectrum, it is a defect belief, or structures that are persistently related for later emergent in psychological problems. Before further reviewing the underlying concepts of the vulnerability, it is essential to understand its connection between relapse condition in unipolar depression and social support (Aziz et al., 2009). Unipolar depression is a mental disorder, distinguished by a persistent low mood and loss of awareness in usual activities (Beck, 1987). Normally, under a certain degree of stressors exposure, an individual with a history of depression will develop a negative cognitive content (thought), associated with the past losses. Such cognitive content is often related to the maladaptive schemas, which in a long run will cause individual's ongoing thought capability to be distorted and later to be dysfunctional (Robinson and Alloy, 2003).

However, this cognitive distortion can be reduced through appropriate supports from other members within the social support network (Heller and Rook, 1997). Social support network is made up of friends, family and peers. Some of it might be professionals and support individuals in very specific ways, or other people in this network might be acquaintances in contact with every day. It has been suggested that social support naturally can help to prevent and decrease stress through positive inferences, which later curbs the formation of cognitive vulnerability (Alloy et al., 2004). However, some literatures have shown that certain supports provide contrast effects. Rather than attenuating the negative effects from stressors, it will eventually amplify the individual's condition to get worse (Coyne, 1990).

In this paper, these positive and negative effects from social support interaction and its relation with cognitive thought are explored. To fulfil this requirement, a dynamic model about cognitive depressogenic thought is proposed. The proposed model can be used to approximate a human's cognitive depressogenic thought progression throughout time. This paper is organized as follows. The first section introduces main concepts and existing theory of cognitive depressogenic thought and hopelessness. Thereafter, a formal model is described and simulated (Section 3 and 4). The model has been verified by a mathematical analysis (Section 5) and by checking properties of simulation traces (Section 6). Finally, Section 7 summarizes the paper with a discussion and future work for this model.

## 2 FUNDAMENTALS IN COGNITIVE DEPRESSOGENIC THOUGHT

People vary in their abilities to overcome stressful life events and it allows them to manage their troubles and not be overwhelmed. These variations answer why the level of severity and duration among different individuals can be diverse in nature. To explain this mechanism, the Extended Hopelessness Theory of Depression is used. In this theory, people who exhibit a negative inferential style, in which they describe, attribute negative events to stable (likely to persist over time) and global (likely to affect many aspects of life) will most likely to infer themselves as fundamentally useless and flawed (Abramson et al. 1999).

Although it is well documented that social support mitigates a risk of relapse, but there is a condition where feedbacks from the social support members may indirectly escalate the risk of relapse. Such feedbacks are considered as "maladaptive inferential feedback" (MIF), and normally increase the negative thought formation (Alloy et al., 2004). Contrary to this, an adaptive inferential feedback (AIF) provides a buffer to reduce the threat, by countering negative inferences for negative event. AIF asserts that when a social support member offers comfort by attributing the source of negative event to be unstable, it will later diminish the risk of creating maladaptive inferences (Dobkin et al. 2004).

In addition, the Extended Hopelessness Theory of Depression relates the development cognitive depressogenic thought through previously described two precursors. First, the present of positive social support feedback (AIF) acts as a buffer to decrease individuals' possibility of having cognitive depressogenic thought over time. Second, individuals with cognitive depressogenic thought will make negative inferences when facing negative events. This condition is also associated with less AIF from the social support members. Moreover, both of these conditions capable to predict changes in stressful events. Therefore, it can be further used to elaborate the immunity level of individuals (as contrast in vulnerability concept). In addition, many studies have also associated the lower risk of depression with the presence of AIF (Coyne, 1990).

As indicated in several previous works, inferential feedbacks provide one of the substantial factors towards the development of cognitive depressogenic thought over time. By combining either one of these two factors together with situational cues, it leads to the formation of either cognitive depressogenic inference or positive attributional style. Situational cues refers to a concept that explains individuals' perception that highly influenced by cues from events (environment). Individuals under the influence of negative thought about themselves will tend to reflect these negative cognitions in response to the occurrence of stressors. These later develop the conditions called "stress-reactive rumination" and "maladaptive inference" (Spasojevic and Alloy, 2001).

Stress reactive rumination reflects a condition where individuals have difficulty in accessing positive information, and further develop a negative bias towards inference (maladaptive inference). This process is amplified by previous exposures towards cognitive depressogenic thought episode. After a certain period, both conditions are related to the formation of hopelessness. Hopelessness is defined by the expectation that desired outcome will not occur, or there is nothing one can do to make it right (Panzarella et al. 2006). Prolong and previous exposure from hopelessness will lead to the development of cognitive depressogenic thought. However, this condition can be reduced by having a positive attributional style, which normally existed during the presence of AIF and low situational cues perception (Crossfield et al. 2002).

In short, the following relations can be identified from the literature: *(1)* prolong exposure towards MIF, negative events, and high-situational cues can lead to the development of cognitive depressogenic thought. *(2)* a proper support (AIF) will reduce the risk of further development of future cognitive depressogenic thought. *(3)* Individuals with high situational cues and proper support will be less effective in reducing the progression of cognitive depressogenic thought, compared to the individuals with less situational cues.

## 3 FORMAL MODEL

This section discusses the details of the dynamic model. In this model, three major components namely; environment, inferential feedbacks, and thought formation will represent the dynamic of interactions between social support feedback and individuals involved in negative thought formation during the beginning of relapse and recurrence in depression. In the formalization, those important concepts are translated into several interconnected nodes. These nodes are designed in a way to have values ranging from 0 (low) to 1 (high). Figure 1

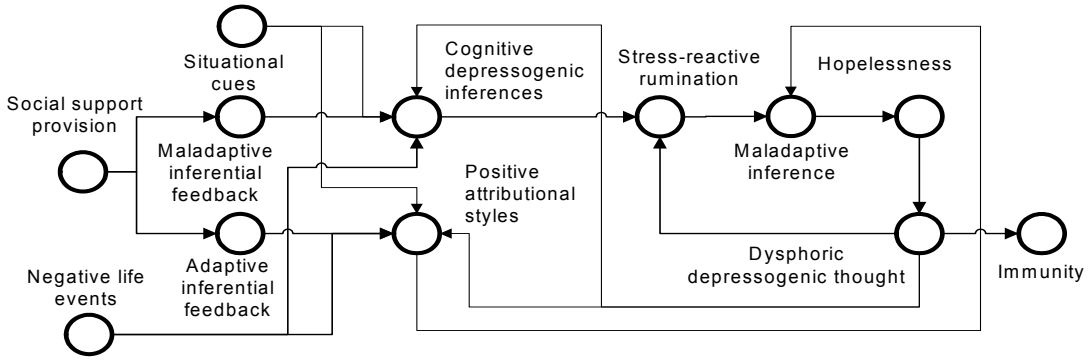


Figure 1: Overview of the Cognitive Depressogenic Thought Model.

depicts the global interaction between these nodes.

## 3.1 Temporal Specification

In order to develop a model, a temporal specification language called LEADSTO and its supporting software environment has been used. LEADSTO enables one to model direct temporal relationship between two state properties (dynamic properties). Consider the format of $\alpha \rightarrow\!\!\!\!\rightarrow_{e,f,g,h} \beta$, where $\alpha$ and $\beta$ are state properties in form of a conjunction of atoms (conjunction of literals) or negations of atoms, and e,f,g,h represents non-negative real numbers. This format can be interpreted as follows;

> If state $\alpha$ holds for a certain time interval with duration g, after some delay (between e and f), state property $\beta$ will hold a certain time interval of length h.

For a more detailed discussion of this language, see (Bosse et al., 2007). To formalize the concepts of properties on dynamics relationship introduced in the previous section (Section 2), for each of them, a logical atom using predicate calculus is introduced. To formalize the dynamic relationship between these concepts, the following temporal relationships are used.

### NEVT: Negative Events

A set of generated events is experienced by an agent X through simulation of several conditions using weighted sum $w$ (where $\sum_w=1$) of life $L$, chronic $C$, and daily $D$ events.

$\forall$X:AGENT
life_event(X,L)$\wedge$ chronic_event(X,C) $\wedge$ daily_event(X,D) $\rightarrow$
neg_event(X, $w_1$.L+ $w_2$.C+ $w_3$.D)

### PTS: Positive Attributional Style

If the agent X faces bad situational cues $B$, negative events $Ne$, cognitive depressogenic thought $Cd$, adaptive inferential style $AiF$, and has a proportional contribution towards positive attributional style $\eta$ then the positive attributional style level is $\eta$*AiF+(1-$\eta$).(1-(B*Ne*Cd)) *AiF

$\forall$X:AGENT
sit_cues(X, B) $\wedge$ neg_event(X, Ne) $\wedge$ adapt_inf(X, AiF) $\wedge$ $\eta$ $\wedge$ cog_dep_tgt(X, Cd) $\rightarrow$
pos_att_style(X, $\eta$*AiF+ (1-$\eta$).(1-(B*Ne*Cd))*AiF )

### CDI: Cognitive Depressogenic Inferences

If the agent X experiences the intensity levels of experiences negative inferential style $MiF$, situational cues $B$, cognitive depressogenic thought $Cd$, negative events $Ne$ and has a proportional contribution towards inferences $\alpha$ then the cognitive depressogenic inferences level is $\alpha$*MiF + (1-$\alpha$).(B*Ne*Cd))*MiF

$\forall$X:AGENT
sit_cues(X, B) $\wedge$ neg_event(X, Ne) $\wedge$ maladap _fb(X, MiF) $\wedge$ $\alpha$ $\wedge$ cog_dep_tgt(X, Cd) $\rightarrow$
cog_dep_inf (X, $\alpha$*MiF + (1-$\alpha$).(B*Ne*Cd))*MiF)

### STR: Stress Reactive Rumination

If the agent X experiences the intensity levels of cognitive depressogenic thought $Cd$, and cognitive depressogenic inference $CDi$ and has a proportional regulator $\beta$ then the stress reactive rumination level is $\beta$* CDi + (1-$\beta$)* Cd

$\forall$X:AGENT
cog_dep_inf (X, CDi) $\wedge$ cog_dep_tgt(X, Cd) $\wedge$ $\beta$ $\rightarrow$
sts_reactive(X, $\beta$* CDi + (1-$\beta$)* Cd )

### MDI: Maladaptive Inference

If the agent X faces stress reactive rumination in SR level and perceives positive attributional style PS level and has a proportional contribution regulator $\gamma$ then the maladaptive inference level is $\gamma$*SR *(1-PS)

$\forall$X:AGENT
sts_reactive(X, SR) $\wedge$ cog pos_att_style(X, PS) $\wedge$ $\gamma$ $\rightarrow$
maladap _inf(X, $\gamma$*SR *(1-PS))

### IMT: Immunity

If the agent X experiences the intensity levels of cognitive depressogenic thought $Cd$, and initially has $BiM$ level of base immunity and has a proportional

regulator $\lambda$ then the immunity level (IM) is $\lambda*BiIM+(1-\lambda)*(1-Cd)*BiM$

$\forall$X:AGENT
cog_dep_tgt (X, Cd) base_im (X, BiM) $\wedge$ $\lambda$ $\rightarrow$
immunity(X, $\lambda$*BiM+(1-$\lambda$)*(1-Cd)*BiM)

### HPS: Hopelessness

If the agent X faces level of maladaptive inference *MDi* and has previous level of hopelessness *Hp* and has adaptation rate $\psi$ then the hopelessness level for agent X after $\Delta t$ is $Hp + (1-Hp)*\psi*(MDi-Hp)*Hp*\Delta t$

$\forall$X:AGENT
maladap _inf(X, MDi) $\wedge$ hoplness(X, Hp) $\wedge$ $\psi$ $\rightarrow$
hoplness(X, (1-Hp)*$\psi$*(MDi-Hp)*Hp*$\Delta$t)

### CDT: Cognitive Depressogenic Thought

If the agent X faces level of hopelessness *Hp* and has previous level of cognitive depressogenic thought *Cd* and has adaptation rate $\varphi$ then the cognitive depressogenic thought level for agent X after $\Delta t$ is $Cd + (1-Cd)*\varphi*(Hp-Cd)*Cd*\Delta t$

$\forall$X:AGENT
hoplness(X, Hp) $\wedge$ cog_dep_tgt (X, Cd)$\wedge$ $\varphi$ $\rightarrow$
cog_dep_tgt (X, Cd + (1-Cd)*$\varphi$*(Hp-Cd)*Cd*$\Delta$t)

## 4 SIMULATION TRACES

In this section, the model was executed to simulate several conditions of agents with the respect of exposure towards negative events, feedbacks from the social support members, and situational cues. With variation of these conditions, some interesting patterns can be obtained, as previously defined in the earlier section. For simplicity, this paper shows several cases of cognitive depressogenic thought levels formation using three different agent attributes. These cases are; (i) an agent ***Heidi*** with a good feedback from the social support members, and using a good judgment about the situation (*B=0.2, MiF=0.1, AiF=0.8)*, (ii) an agent ***Kees*** that receives good feedbacks but with bad judgment about the situation (*B=0.8, MiF=0.1, AiF=0.9)*, and (iii) an agent ***Piet*** with bad feedbacks from the social support, and bad judgment about the situation (*B=0.9, MiF=0.8, AiF=0.1*). The duration of the simulated scenario is up to $t$ = 1000 (to represent the conditions within 42 days) with two negative events. The first event consisted of the prolonged and gradually decreased stressors, while the second event dealt with the decreased stressor. For all conditions, the initial cognitive depressogenic thought was initialized as 0.5.

### Case #1: Prolonged Repeated Stressor with Different Individuals Inferential Feedback and Situation Cues

During this simulation, each type of individual attribute has been exposed to a prolonged stressor condition. The result of this simulation is shown in Figure 2.

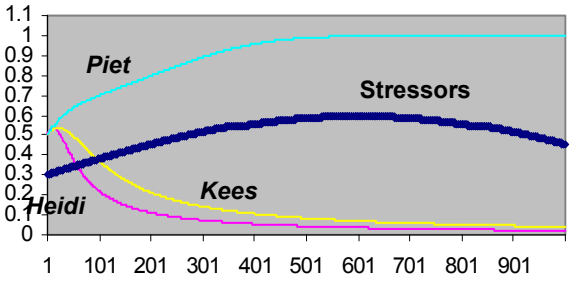


Figure 2: Cognitive Depressogenic Level for Each Individual during Prolonged Stress Events.

In this simulation trace, it shown that *Piet* (*high situational cues,* and *negative inferential feedback*) tends to develop a cognitive depressogenic thought, in contrast with the others. *Heidi* (*low situational cues,* and *positive inferential feedback*) shows a rapid declining pattern in developing the cognitive condition. Note that *Kees* (*high situational cues* and *positive inferential feedback*) has also developed a decreasing pattern towards the cognitive condition. However, *Kees* has a lesser decreasing effect towards a negative thought despite a high positive support, given that this individual tends to perceive negative view about the situation. Persistent positive support from the social support members helps each agent to reduce the development of cognitive thought throughout time

### Case #2: Decreased Stressor with Different Individual Inferential Feedback and Situational Cues

In this simulation trace, there are two conditions were introduced, one with a very high constant stressor, and with no stressor event. These events simulate the condition of where agents were facing a sudden change in their life, and how inferential feedbacks and perceptions towards events play important to role towards the diminishing of cognitive thought. The result of this simulation is shown in Figure 3.

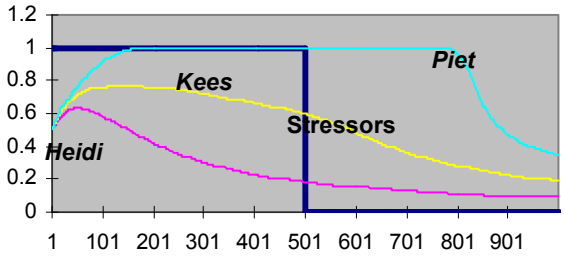


Figure 3: Cognitive Depressogenic Level for Each Individual during Fluctuated Stressors.

A comparison for each agent shows that *Piet* gets into a sharp progression towards a high cognitive thought after direct exposure towards a heighten stressor. At the start of a high constant stressor, both individuals *Heidi* and *Kees* develop cognitive thought. However, after certain time points, those progressions dropped and reduced throughout time. As for *Piet*, even the stressors have been diminished, the level cognitive depressogenic thought was still high for several time points until it decreased.

# 5 MATHEMATICAL ANALYSIS

By a mathematical formal analysis, the equilibria of the model can be determined. The equillibria explains condition where the values for the variables which no change occur. Assuming all parameters are non-zero, the list of LEADSTO specifications for the case of equilibrium for the agent X are:

$$dCd(t)/dt=(1-Cd)*\varphi*(Hps-Cd)*Cd \quad (1)$$

$$dHp(t)/dt = (1-Hp)*\psi*(MDi-Hp)*Hp \quad (2)$$

Assuming both adaptation rates are equal to 1, therefore, these are equivalent to;

$$Cd=1 \text{ or } Hp=Cd \text{ or } Cd=0 \quad (3)$$

$$Hp=1 \text{ or } MDi=Hp \text{ or } Hp=0 \quad (4)$$

From here, a first of conclusions can be derived where the equilibrium can only occur when the $Cd=1$, $Hp=Cd$, or $Cd=0$ (refer to Equation 3). In this paper, only condition $Cd=1$, has been chosen for the discussion. From this case ($Cd=1$), it can be further derived that respective values for the equilibrium condition to take place. These values can be calculated from the following formulae.

$$CDi = \alpha*MiF + (1-\alpha)*(B*Ne*Cd)*MiF$$

$$PS = \eta*AiF + (1-\eta)* (1-(B* Ne*Cd)).AiF$$

$$SR = \beta*[\alpha*MiF + (1-\alpha)*(B*Ne*Cd)*MiF] + (1-\beta)$$

$$MDi = \gamma*[\beta*(\alpha*MiF + (1-\alpha)*(B*Ne*Cd)*MiF] +(1-\beta))*(1-(\eta*AiF+(1-\eta)*(1-(B* Ne*Cd)))*AiF)]$$

$$IM = \lambda* BiM$$

This equillibria describes the condition when agents are experiencing an intense negative cognitive thought throughout time will eventually have their level immunity reduced to the lowest boundary of agents' limit. This condition creates higher vulnerability towards the development of onset during the present of negative events. Simulation trace from the experiment #1 confirms this condition

# 6 AUTOMATED VERIFICATION

This section deals with the verification of relevant dynamic properties of the cases considered in the human agent model, which coherence with the literatures. The Temporal Trace Langue (TTL) is used to perform an automated verification of specified properties against generated traces. TTL is designed on atoms, to represent the states, traces, and time properties. This relationship can be presented as a *state(γ, t, output(R))* |= *p*, means that state property *p* is true at the output of role *R* in the state of trace *γ* at time point *t* (Bosse et al., 2009). Based on that concept, several dynamic properties can be formulated using a sorted predicate logic approach. Below, a number of them are introduced in semi formal and in informal representations.

### VP1: Positive Supports will Reduce the Risk in Developing Future Depressogenic Thought

When an agent X received more positive supports from its social support networks, then the agent will unlikely to develop further hopelessness in future.

∀γ:TRACE, t, t':TIME, R1,R2,R3,MIN_LEVEL:REAL, X:AGENT
[ state(γ, t) |= adapt_inf (X, R1) & R1 > MIN_LEVEL
state(γ, t) |= cog_dep_tgt (X,R2) & R2 > 0]
⇒ ∃t':TIME > t:TIME
[state(γ, t') |= cog_dep_tgt (X,R3) & R3 < R2]

This property can be used to verify future condition of an agent if the agent receives positive supports from its social support members throughout time. Many research works have maintained that positive supports from members will decrease possibilities of having further negative thought in future (Heller and Rook, 1997).

### VP2: Negative Perception towards Situation and Bad Support received from the Social Support Networks will Increase the Risk of Further Depressogenic Thought

When an agent X perceives all situations will give negative impact and an agent X receives bad support from its social support networks, then the agent X

will almost likely to develop future depressogenic thought.

∀γ:TRACE, t, t':TIME, R1,R2,R3,R4, MIN_MLD_LEVEL, MIN_SC_LEVEL, MAX_CDT_LEVEL:REAL, X:AGENT
[state(γ, t) |= maladap_bf (X, R1) &
R1 > MIN_MLD LEVEL &
state(γ, t) |= sit_cues(X, R2) & R2 > MIN_SC_LEVEL &
state(γ, t) |= cog_dep_tgt (X,R3) & R3 < MAX_CDT_LEVEL]
⇒ ∃t':TIME > t:TIME
[state(γ, t') |= cog_dep_tgt (X,R4) & R4 > R3]

By checking property VP2, one can verify whether negative perception (situational cues) and bad support will influence the rise of depressogenic thought. It is particularly significant to observe this property in the model given that bad support and negative perception is highly correlated towards the development of depressogenic thought (Crossfield et al., 2002).

# 7 CONCLUSIONS

In this paper, the assumed role of negative cognitive content in depression is explained. Based on this, a agent-model is presented that describes the temporal relation between personal characteristics, negative life events and social support. This model is used in a small simulation to investigate the effect of different types of support on different persons that undergo similar life events. The mathematical analysis of the model and the verification of expected behaviour of the modelled agents in the simulation traces give some evidence for the appropriateness of the model.

In the future, we would like to extent the model with the effect of negative thoughts and a bad mood on the willingness to offer support. Together with the existing elements of the model, this would allow for a multi-agent simulation of a larger community, in which different persons interact with each other by giving and receiving support. Such analysis would make it possible to investigate the consequences of depressive persons in a small community.

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# REFERENCES

Abramson, L.Y., Alloy, L.B., Hogan, M.E., Whitehouse, W.G., Donovan, P., Rose, D.T., Panzarella, C., Raniere, D. 1999. *Cognitive vulnerability to depression: Theory and evidence*. Journal of Cognitive Psychotherapy, 13, 5-20.

Alloy, L. B., Abramson, L. Y., Gibb, B. E., Crossfield, A. G., Pieracci, A. M., Spasojevic, J., Steinberg, J. A. 2004. *Developmental antecedents of cognitive vulnerability to depression: Review of findings from the cognitive vulnerability to depression project.* Journal of Cognitive Psychotherapy, 18(2), 115-133.

Aziz, A.A., Klein, M.C.A., Treur, J. 2009. An agent model of temporal dynamics in relapse and recurrence in depression. In: Ali, M., Chen, S.M., Chien, B.C., Hong, T.P. (eds.), *IEA-AIE 2009*. LNAI, Springer Verlag, pp. 36-45.

Beck, A.T. 1987. *Cognitive models of depression,* Journal of Cognitive Psychotherapy 1, pp. 5–37.

Bosse, T., Jonker, C.M., Meij, L. van der, Treur, J. 2007. *A language and environment for analysis of dynamics by simulation*. International Journal of Artificial Intelligence Tools, vol. 16, pp. 435-464.

Bosse, T., Jonker, C.M., Meij, L. van der, Sharpanskykh, A., Treur, J. 2009. *Specification and verification of dynamics in agent models*. International Journal of Cooperative Information Systems, vol.18, pp.167 - 193

Coyne, J.C. 1990. *Interpersonal process in depression*. In: G.I. Keitner, Editor, Depression and families: Impact and treatment, American Psychiatric Press, Washington, DC , pp. 31–53.

Crossfield, A. G., Alloy, L. B., Gibb, B. E., Abramson, L. Y. 2002. The development of depressogenic cognitive styles: The role of negative childhood life events and parental inferential feedback. *Journal of Cognitive Psychotherapy*, *16*(4), 487–502.

Dobkin, R.D, Panzarella, C., J. Fernandez, Alloy, L.B., Cascardi, M. 2004. *Adaptive inferential feedback, depressogenic inferences, and depressed mood: A laboratory study of the expanded hopelessness theory of depression,* Cognitive Therapy and Research, pp. 487–509.

Heller, K., Rook, K.S. 1997. *Distinguishing the theoretical functions of social ties: Implications for support interventions.* In: S. Duck, Editor, Handbook of personal relationships: Theory, research, and interventions, John Wiley and Sons, Chichester, England, pp. 649–670.

Panzarella, C., Alloy, L.B., Whitehouse, W.G. 2006. *Expanded hopelessness theory of depression: On the mechanisms by which social support protects against depression,* Cognitive Therapy and Research 30 (3), pp. 307–33

Robinson, M. S., Alloy, L. B. 2003. *Negative cognitive styles and stress-reactive rumination interact to predict depression: A prospective study*. Cognitive Therapy & Research, 27(3), 275-292.

Spasojevic, J., Alloy, L. B. 2001. *Rumination as a common mechanism relating depressive risk factors to depression*. Emotion, 1(1), 25-37.