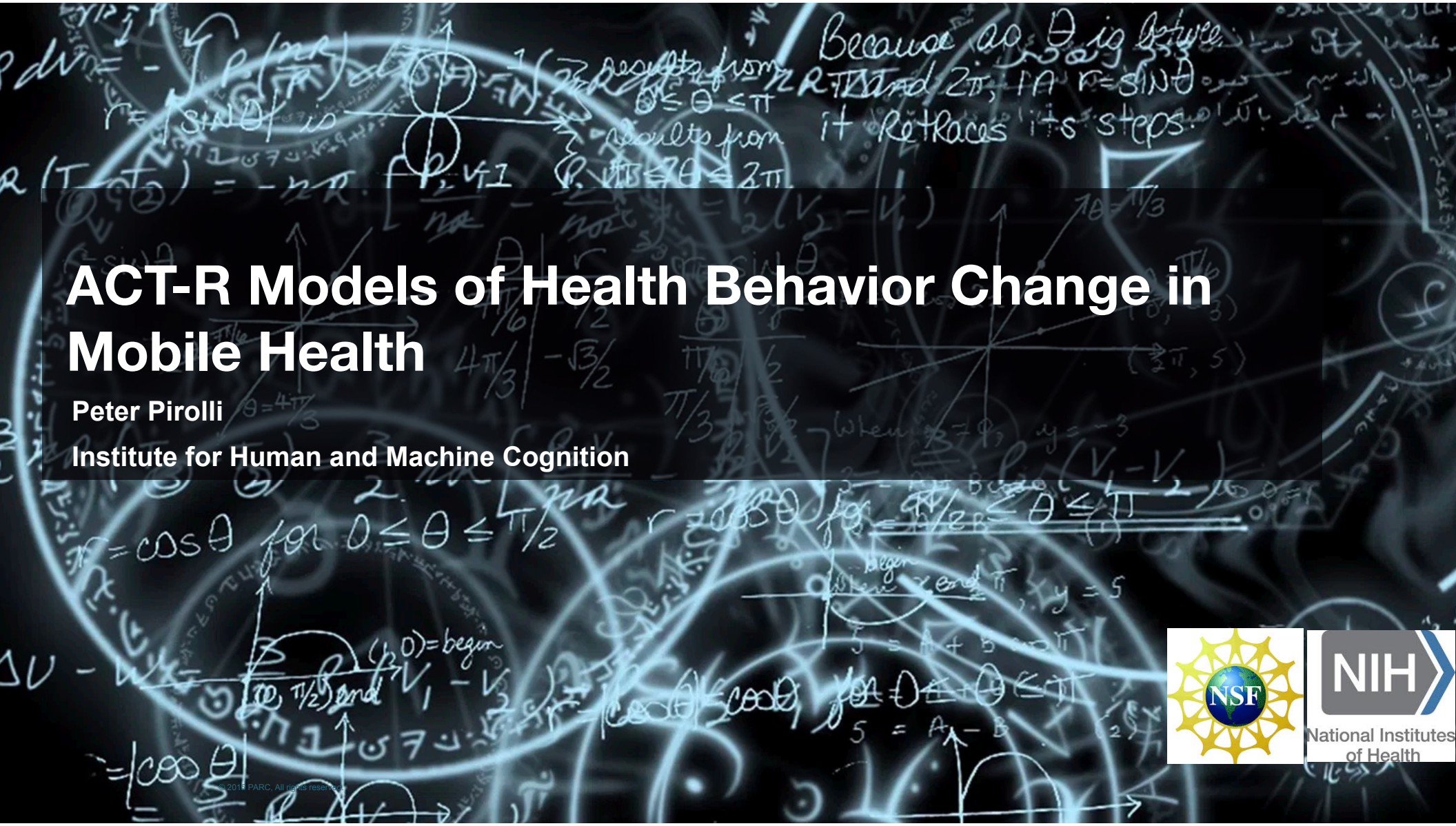


ACT-R Models of Health Behavior Change in Mobile Health

Peter Pirolli

Institute for Human and Machine Cognition

Lifestyle Change (Behavior Change)

- Behavioral and environmental factors account for more deaths than genetics
- 70% of health care costs are due to changeable behavior (diet, fitness, smoking). Estimates range from $500B - $1 Trillion/YR
- Opportunity for digital innovations and evidence-based interventions that are:
  - Accessible, scalable, replicable, and sustainable

http://www.nahu.org/legislative/policydocuments/NAHUWhitePaperCost.pdf

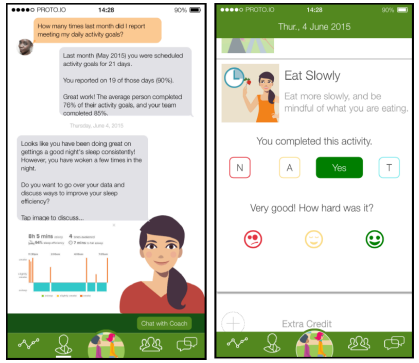
Riley, W. T., Nilsen, W. J., Manolio, T. A., Masys, D. R., & Lauer, M. (2015). News from the NIH: Potential contributions of the behavioral and social sciences to the precision medicine initiative. *Translational behavioral medicine, 5*(3), 243-246. doi:10.1007/s13142-015-0320-

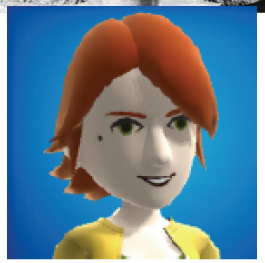
Outline

- Overview of Fittle mHealth app
- Self-efficacy Model
  - *Instance-Based Learning (IBL)*
- Implementation Intention Model
  - *Base-level learning*
  - *Habit compilation*
  - *Utility learning*

Aims

#1346066 #5R01AG053163-02



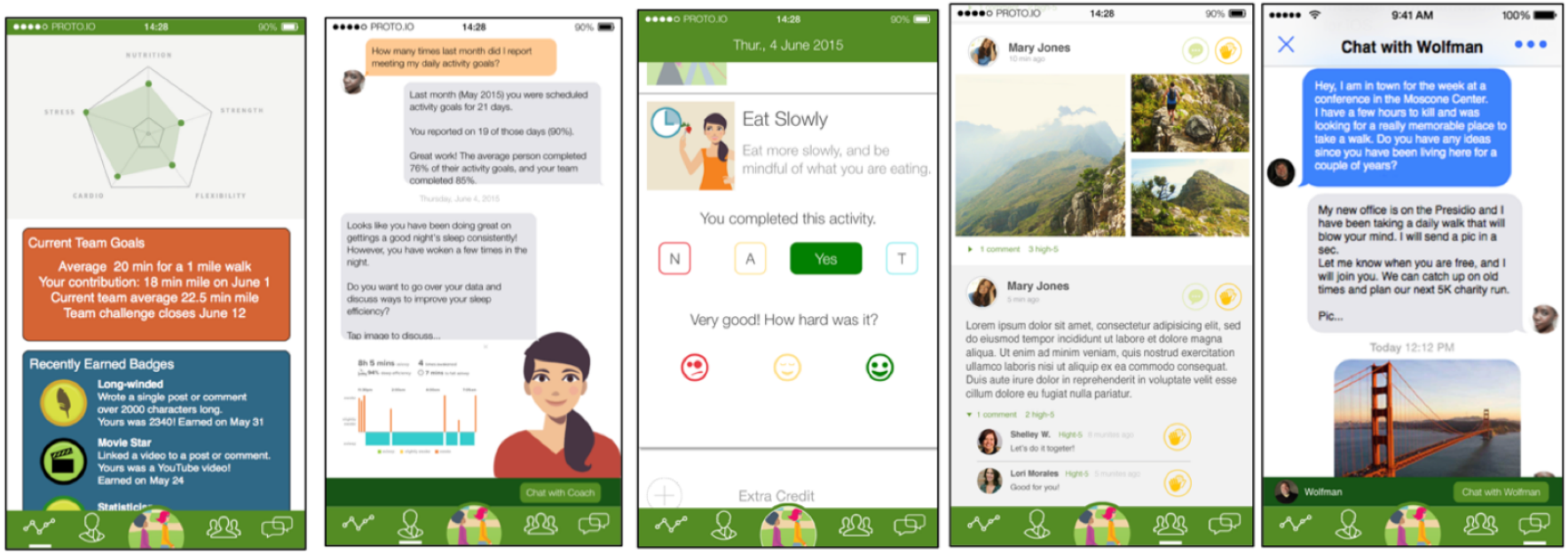


- **Scaffolding interventions to build healthy habits**. Smartphone platforms to integrate behavior-change techniques into everyday life to improve diet & fitness

- **Integrated fine-grained predictive theory and methods**. Computational cognitive models to understand and predict habit change

- Support **intelligent coaching**

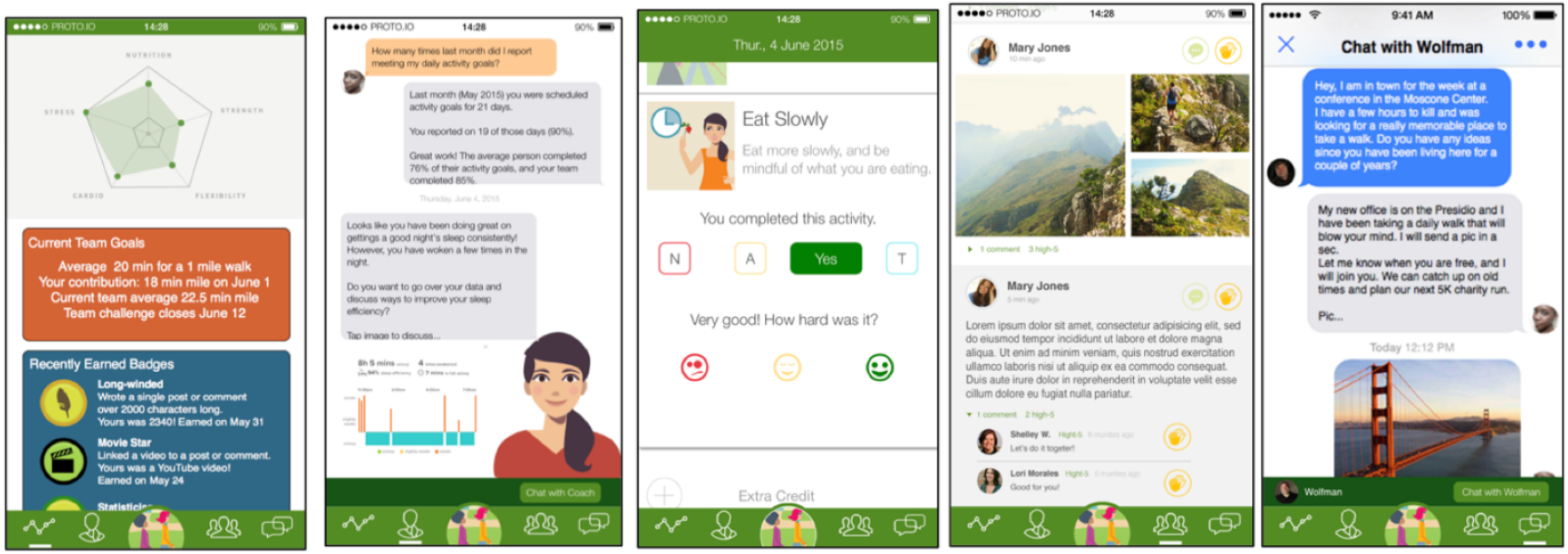
Recent Version



Main Dashboard

Daily Goal &
Reporting

Recent Version

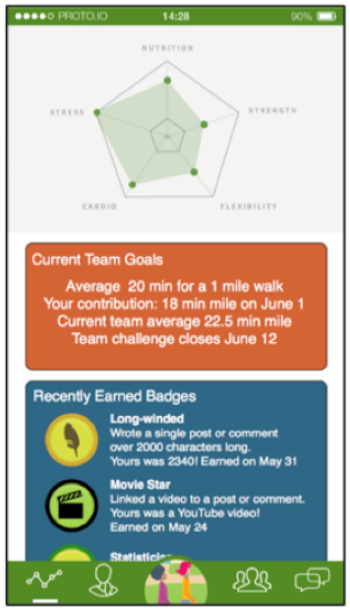


Virtual Coach

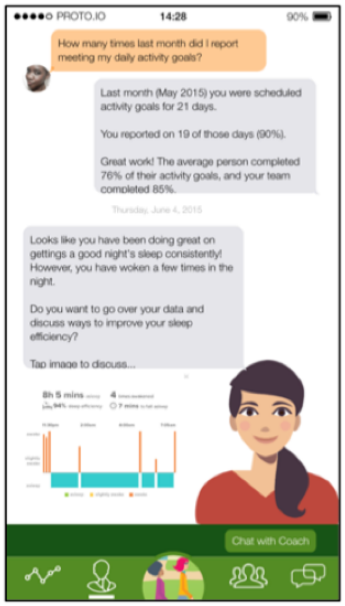
Main Dashboard

Daily Goal &
Reporting

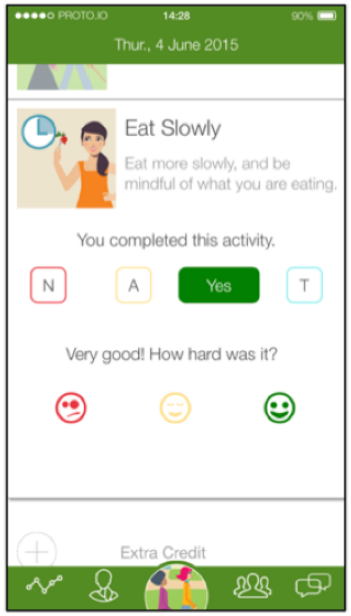
Recent Version



Analytics



Virtual Coach



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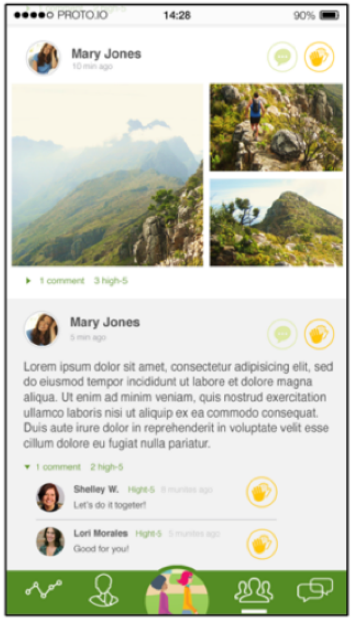
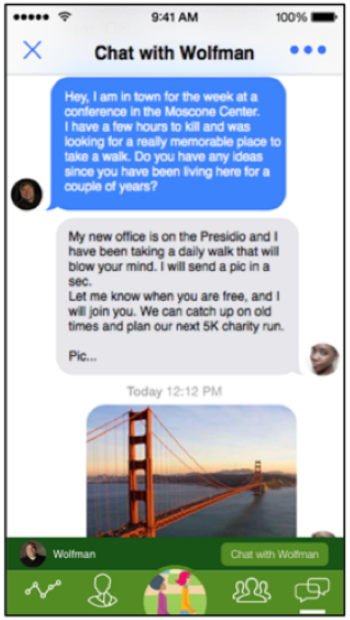
Daily Goal &
Reporting





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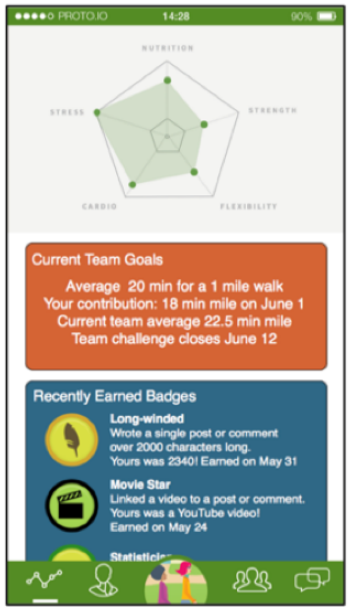
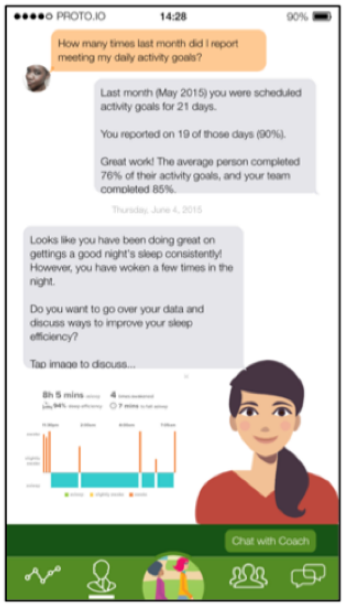
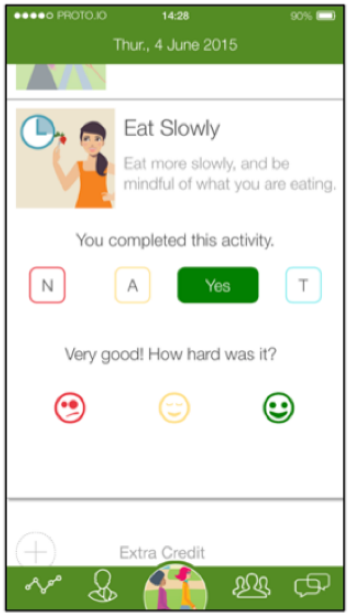
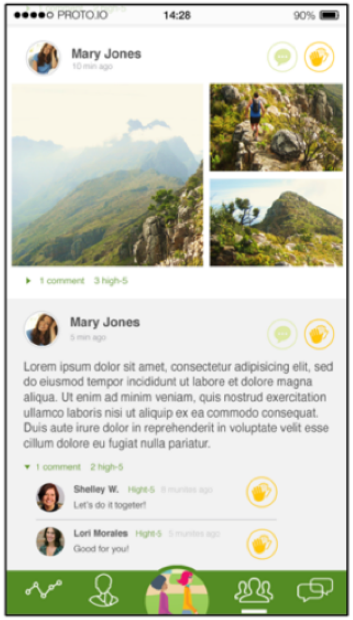
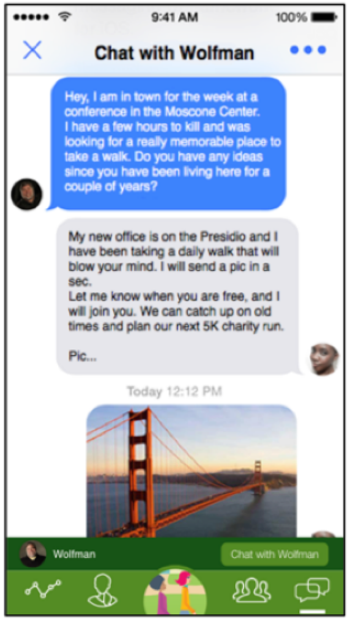






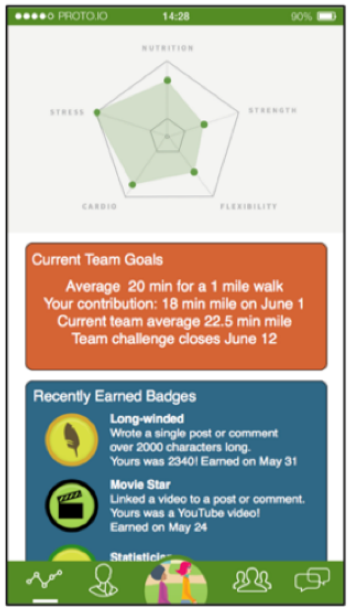




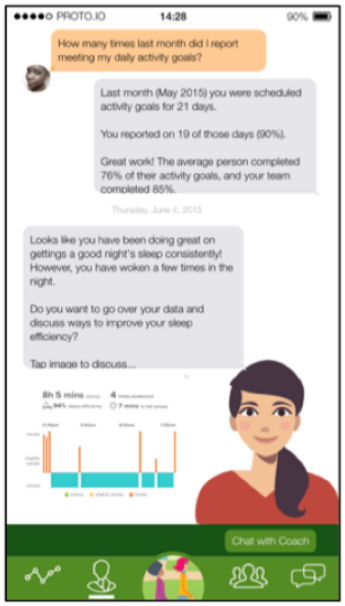
[Analytics](#) [Virtual Coach](#) [Main Dashboard](#) [Team Chat](#)

Daily Goal & Reporting

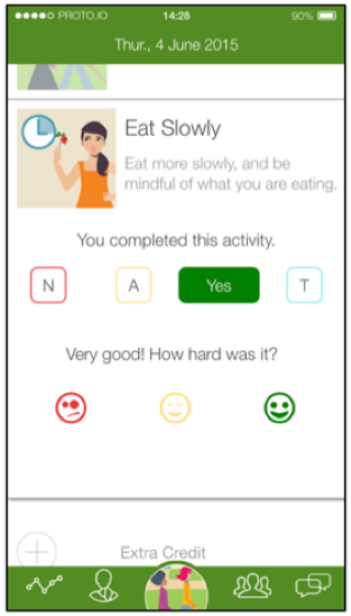
Recent Version



Analytics

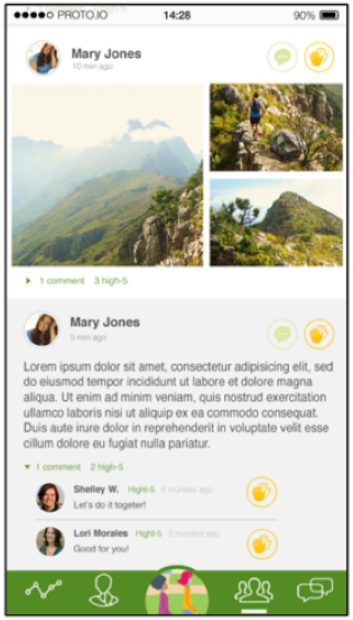


Virtual Coach

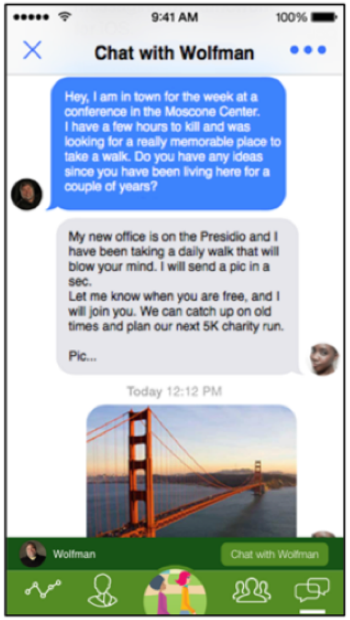


Main Dashboard

Daily Goal & Reporting

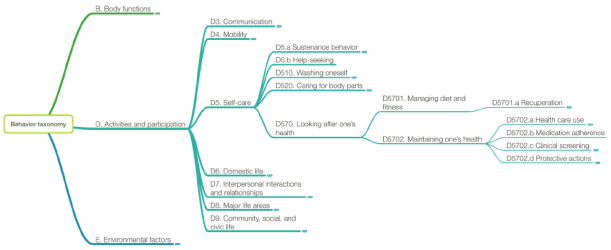


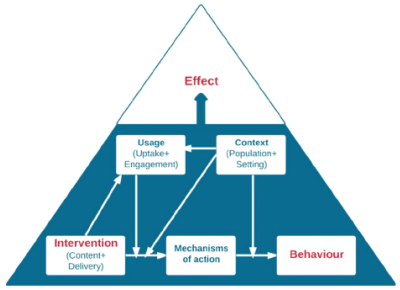
Team Chat

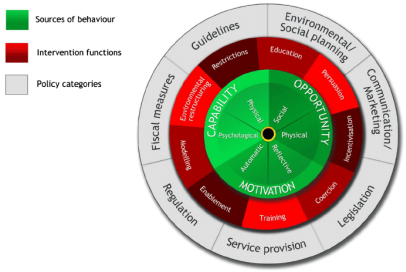


Peer-to-peer

Complex “Theory” Space:
Evidence-Based Behavior Change Interventions







Behavior Change Taxonomy (Michie et al., 2013)

- 93 Behavior change techniques (BCTs)
- 83 Theories
- 26 Mechanisms of Action
- 1725 Constructs

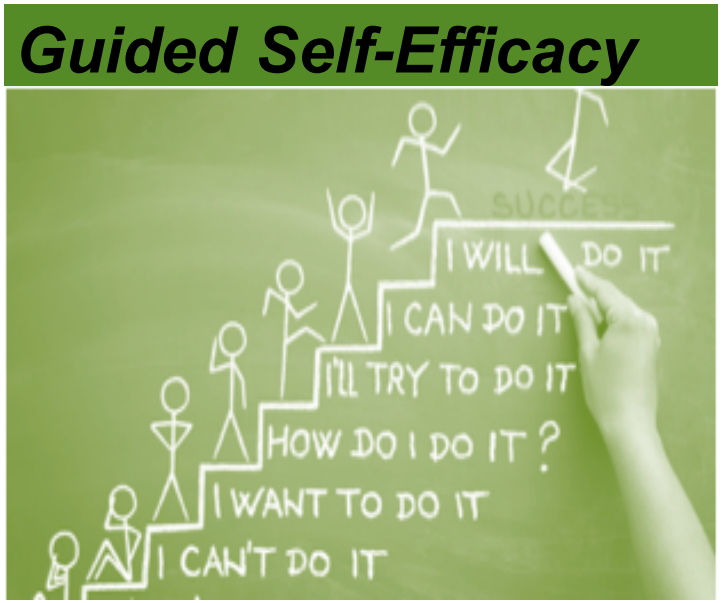
Meta-analysis of the taxonomy (Samdal et al., 2017)

- Estimate effects sizes of BCTs

S. Michie, M. Richardson, M. Johnston, C. Abraham, J. Francis, W. Hardeman, *et al.*, "The Behavior Change Technique Taxonomy (v1) of 93 Hierarchically Clustered Techniques: Building an International Consensus for the Reporting of Behavior Change Interventions," *Annals of Behavioral Medicine,* vol. 46, pp. 81-95, 2013.

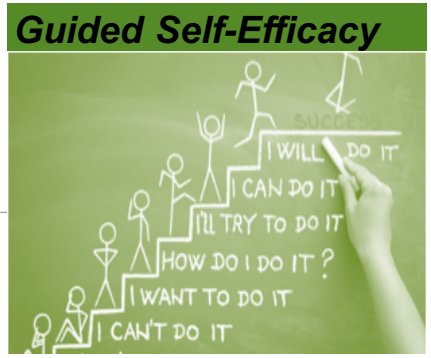
Samdal, G. B., Eide, G. E., Barth, T., Williams, G., & Meland, E. (2017). Effective behaviour change techniques for physical activity and healthy eating in overweight and obese adults; systematic review and meta-regression analyses. *Int J Behav Nutr Phys Act, 14*(1), 42. doi:10.1186/s12966-017-0494-y

Guided Self-Efficacy



Pirolli, P. (2016). A Computational Cognitive Model of Self-efficacy and Daily Adherence in mHealth. *Translational Behavioral Medicine.*

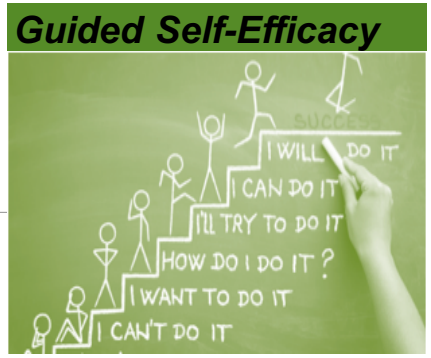
Guided Self-Efficacy



If the bar is set too high….
my self-efficacy is low…
I won't do it

Pirolli, P. (2016). A Computational Cognitive Model of Self-efficacy and Daily Adherence in mHealth. *Translational Behavioral Medicine.*

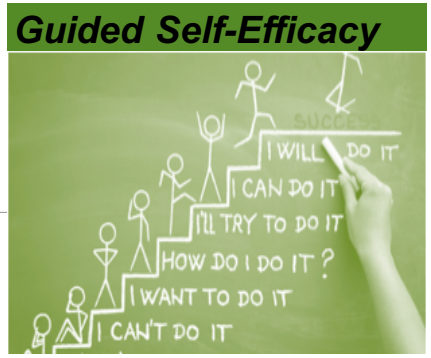
Guided Self-Efficacy



Set the bar lower….
my self-efficacy is **high**…
I will do it!

Pirolli, P. (2016). A Computational Cognitive Model of Self-efficacy and Daily Adherence in mHealth. *Translational Behavioral Medicine.*

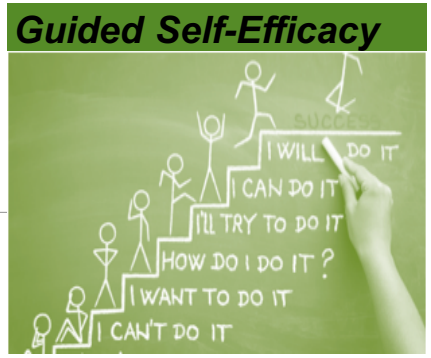
Guided Self-Efficacy



Self-efficacy has grown…
I can set the bar higher!

Pirolli, P. (2016). A Computational Cognitive Model of Self-efficacy and Daily Adherence in mHealth. *Translational Behavioral Medicine.*

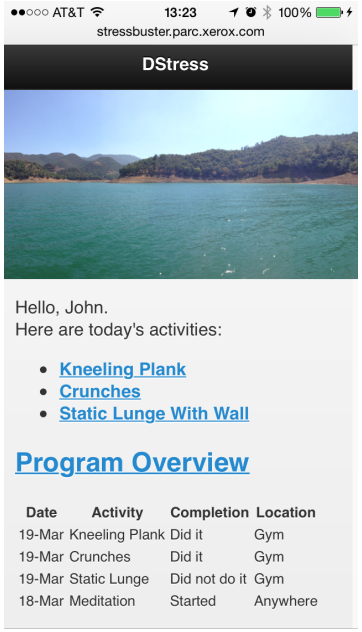
Guided Self-Efficacy



..and eventually higher than I ever thought

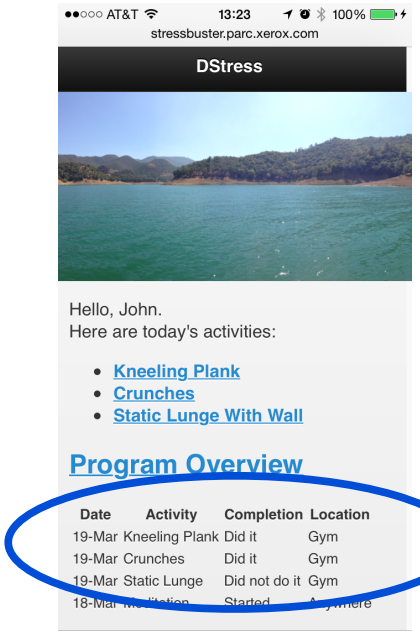
Pirolli, P. (2016). A Computational Cognitive Model of Self-efficacy and Daily Adherence in mHealth. *Translational Behavioral Medicine.*

Testing the Model in a Study of DStress: Stress Reduction through Exercise & Meditation



Konrad, A., Bellotti, V., Crenshaw, N., Tucker, S., Nelson, L., Du, H., . . . Whittaker, S. (2015). *Finding the Adaptive Sweet Spot: Balancing Compliance and Achievement in Automated Stress Reduction.* Paper presented at the SIGCHI Conference on Human Factors in Computing Systems (CHI 2015), Seoul, Korea.

DStress:
Stress Reduction through Exercise & Meditation



46 Exercises

Upper body, lower body, circuit

Konrad, A., Bellotti, V., Crenshaw, N., Tucker, S., Nelson, L., Du, H., . . . Whittaker, S. (2015). *Finding the Adaptive Sweet Spot: Balancing Compliance and Achievement in Automated Stress Reduction.* Paper presented at the SIGCHI Conference on Human Factors in Computing Systems (CHI 2015), Seoul, Korea.

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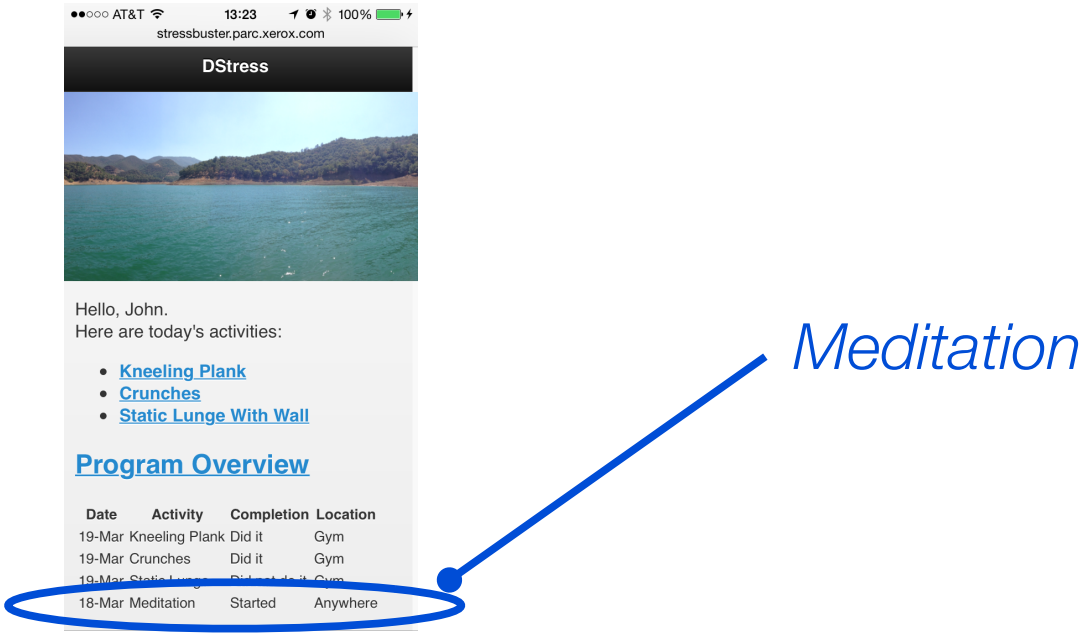

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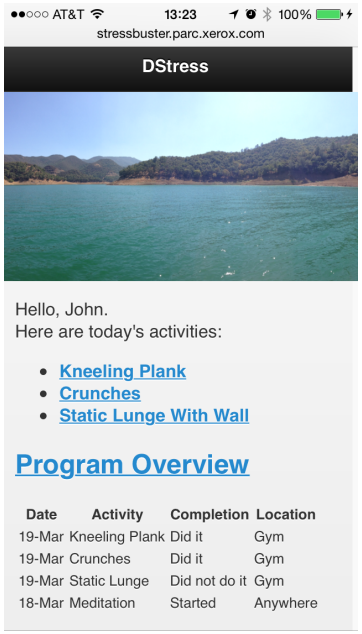

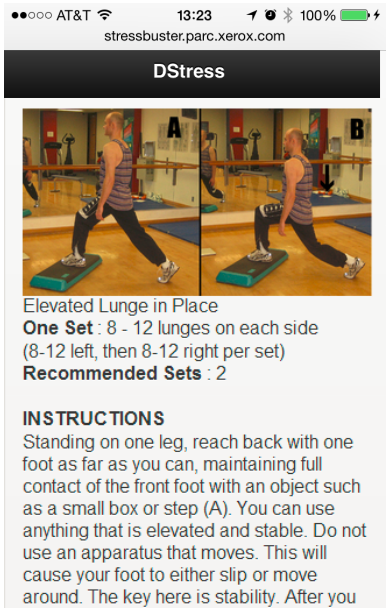

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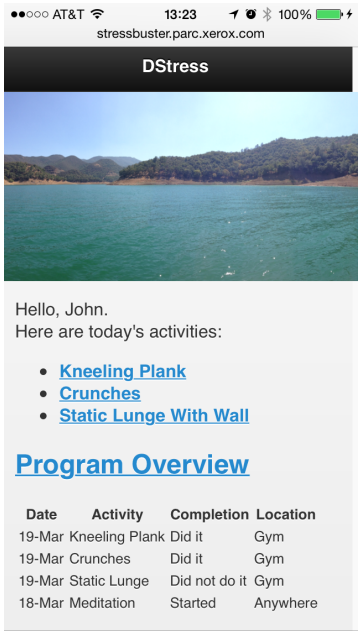

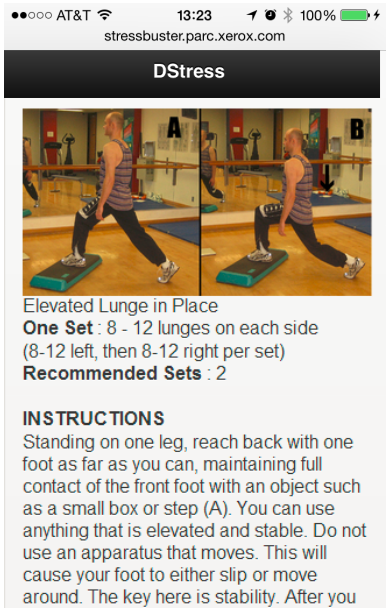

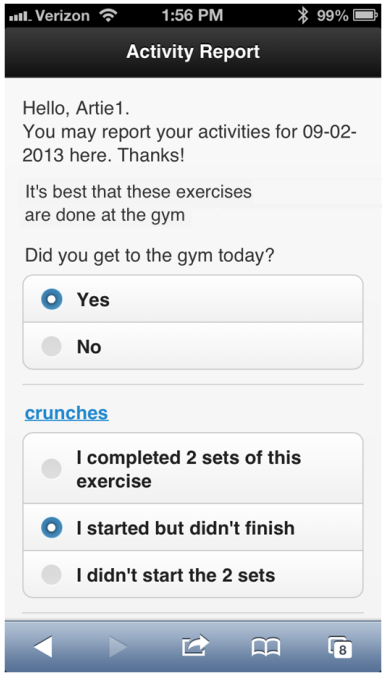

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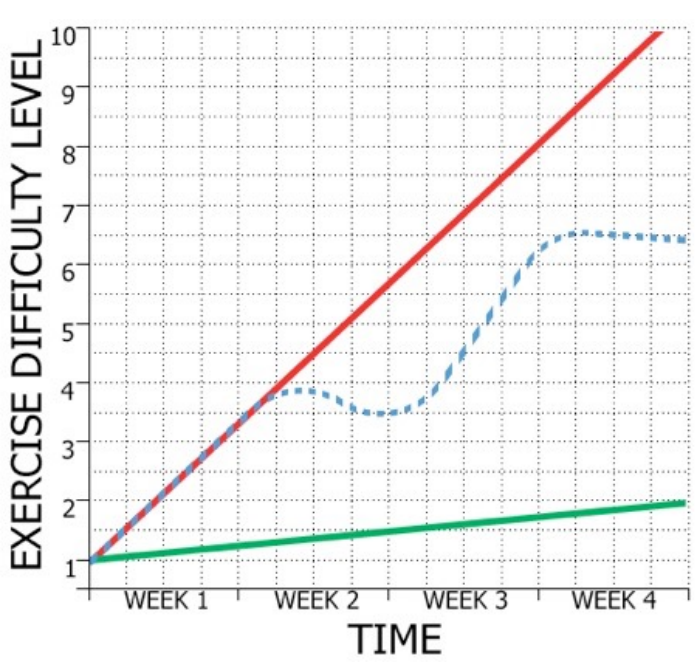
DStress Study

N = 65 (42 Female)
Aged 19-59 (*M* = 31)



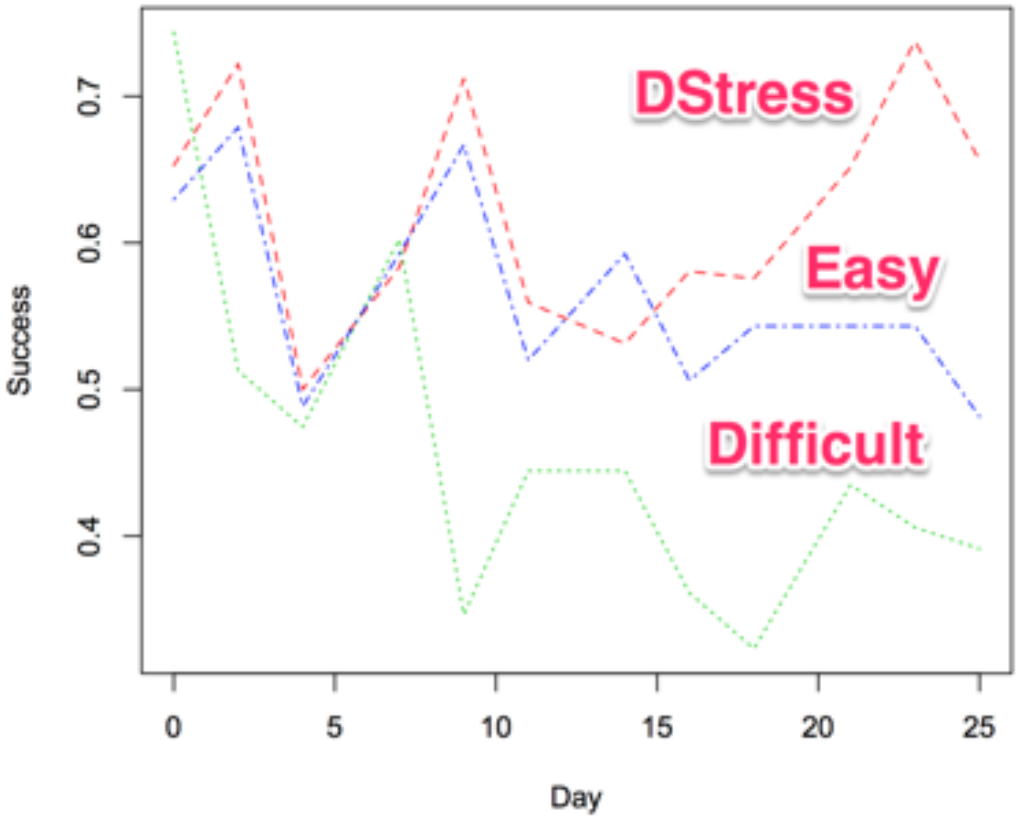
Difficult - Fixed Schedule

Adaptive Schedule

Easy - Fixed Schedule

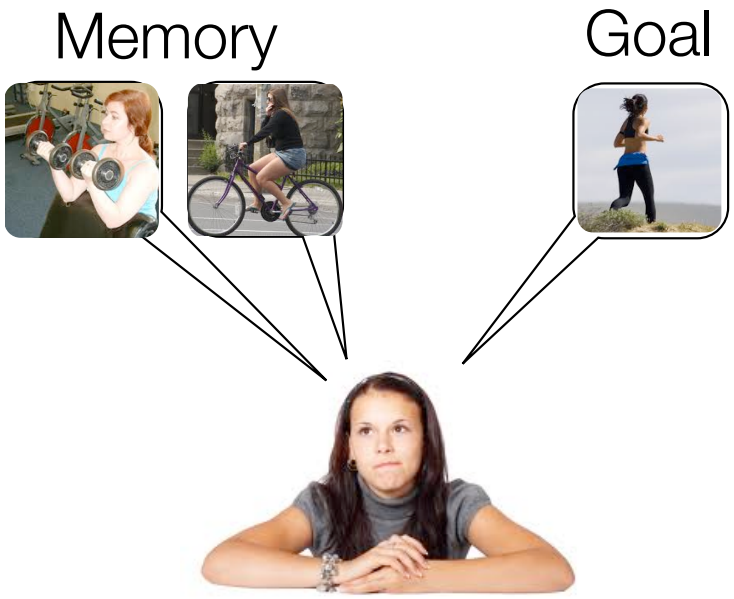
Konrad, A., Bellotti, V., Crenshaw, N., Tucker, S., Nelson, L., Du, H., . . . Whittaker, S. (2015). *Finding the Adaptive Sweet Spot: Balancing Compliance and Achievement in Automated Stress Reduction.* Paper presented at the SIGCHI Conference on Human Factors in Computing Systems (CHI 2015), Seoul, Korea.

Adjustable (Personalized) Schedules of Behavioral Goals Achieve Higher Compliance



Intuitions Behind the Self-Efficacy/Motivation Model

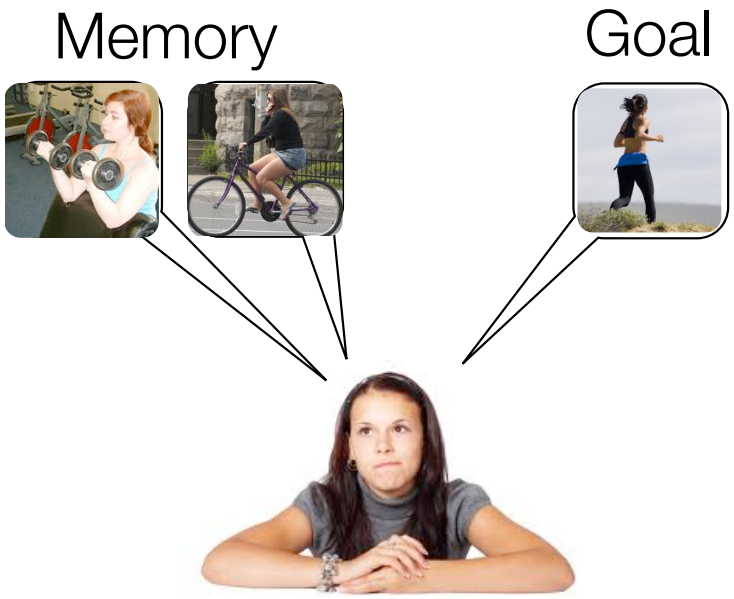
- I'm considering the **goal** to do a set of activities ***A*** that I believe have some difficulty $\boldsymbol{\delta_g}$
- Call upon **memory**: What have I done that is **similar to *A*** & what was the difficulty of those past experiences?
- **Perceived self-efficacy**: Based on the difficulty of my successful past experiences, I believe my ability is $\boldsymbol{\theta_E}$
- I **predict my goal success** to be



P(success) ~ $f(\boldsymbol{\theta_E} - \boldsymbol{\delta_g} + \textit{intentional effort})$

Intuitions Behind the Self-Efficacy/Motivation Model

- If **self-efficacy is high**, predicted success is high, then **DO IT**



Intuitions Behind the Self-Efficacy/Motivation Model

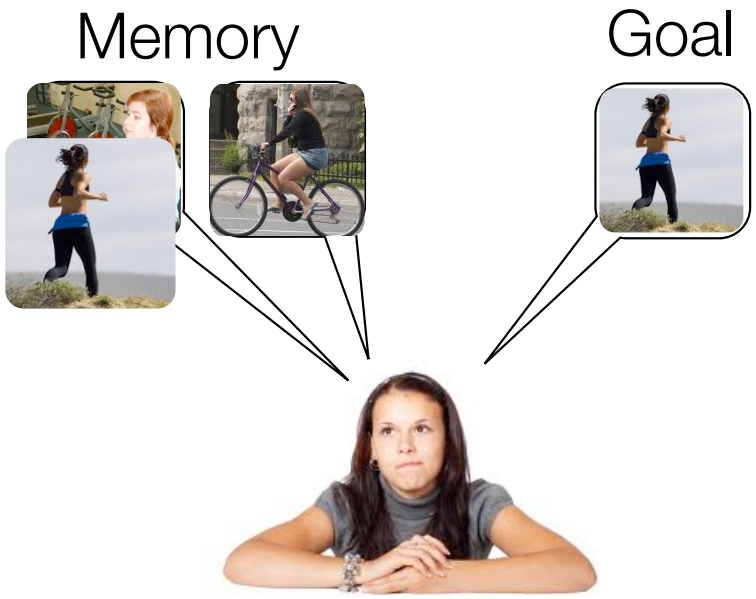
- If **self-efficacy is high**, predicted success is high, then **DO IT**

DO IT!

Intuitions Behind the Self-Efficacy/Motivation Model

- If **self-efficacy is high**, predicted success is high, then **DO IT**

- **Each new successful experience goes into memory and affects the next assessment of self-efficacy**



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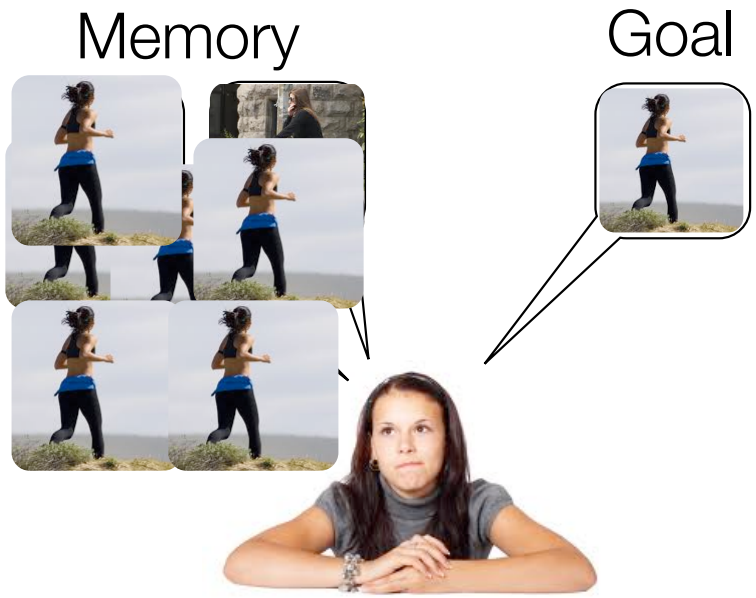
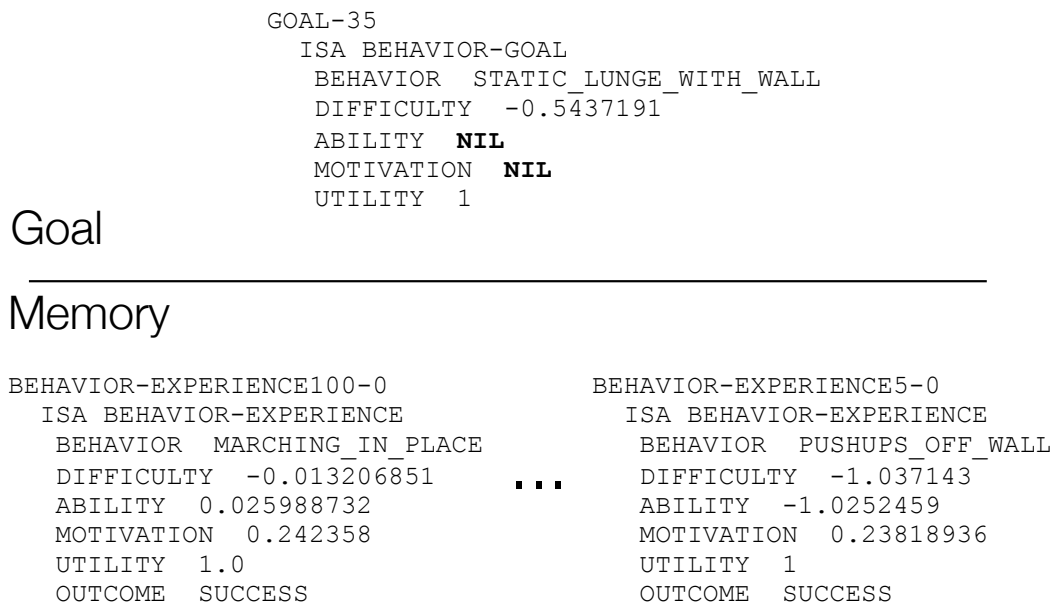


Goals and Memory Chunks in ACT-R

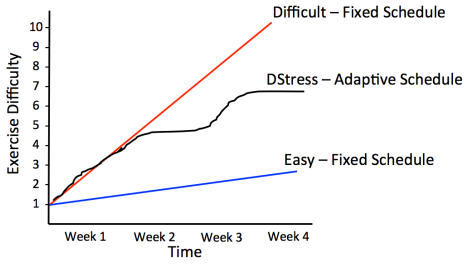


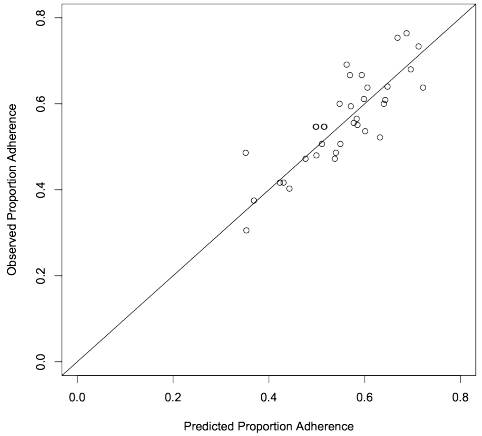
Fit of ACT-R-Based Model
28-day Dstress Study of Personalized Goal Adjustment

Exercise adherence improves when goal difficulty is adaptively adjusted.

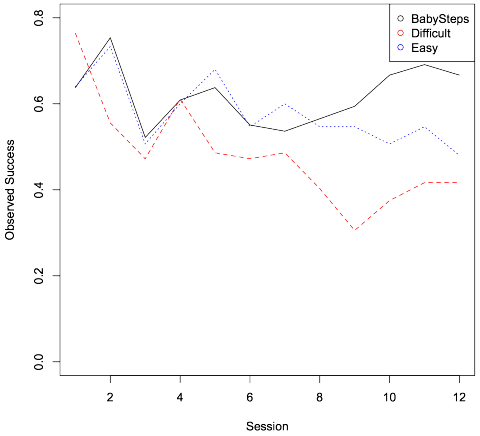
Builds self-efficacy

ACT-R default parameters

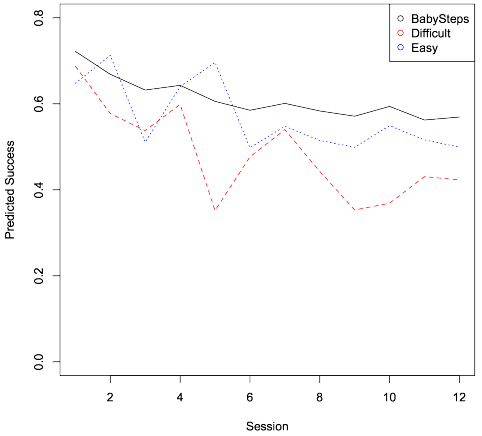




Data



Model



Implementation Intentions

- Mental representations of simple plans to translate goal intentions into behavior

- People asked to specify
  - IF *I encounter situation S* THEN *I will do action A*
  - "If it's 5:30 p.m. on a weekday, then I'll go out for a forty-minute walk"

- Medium-to-large effect size (d = 0.65) that is superior to interventions focused on increasing commitment to goal intentions (~ d = 0.33)

Underlying Cognition

Implementation Intention

IF_____

THEN__

- Mental representations of the *situation* in which the intended behavior is to take place become *more accessible*
- Strong *associative link* between situation and behavioral action effects *heightened readiness* and *less effort* to perform
- Priming manipulations increase the effects of implementation intentions
- Suggests declarative memory mechanisms
- mHealth reminders (e.g., SMS) affect memory
- ACT-R should predict effects of reminders on strength of implementation intentions and behavior change

ACT-R Model of Goal-striving + Habit Formation

- **Goal Intentions**: Prospective memory = a goal-like representation that you've put away in memory to be turned into a goal in response to the right context

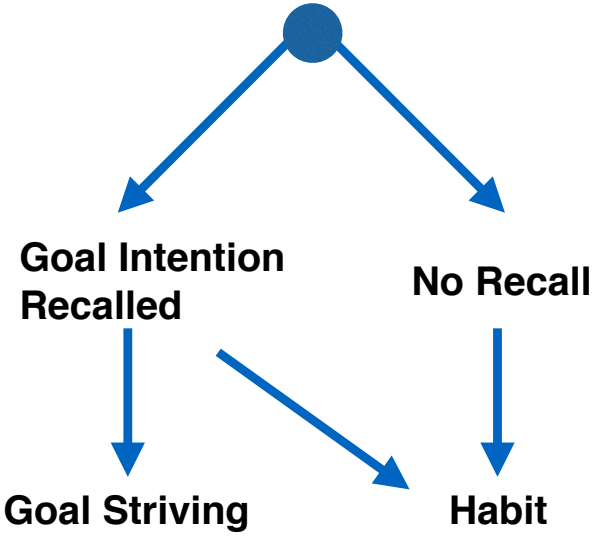
- **Implementation intentions** = plan-like representations that you've stored away in memory to be turned into concrete behaviors

- **Reminders** (pamphlets, tips, calendar notifications....) boost the activation of goal intentions and implementation intentions so that they are more likely to be retrieved in the right context

- **Habit compilation** (knowledge compilation): Execution of complex sequences of steps (multiple production rules, multiple memory retrievals) produce new, simpler production rules that require less cognition the next time around

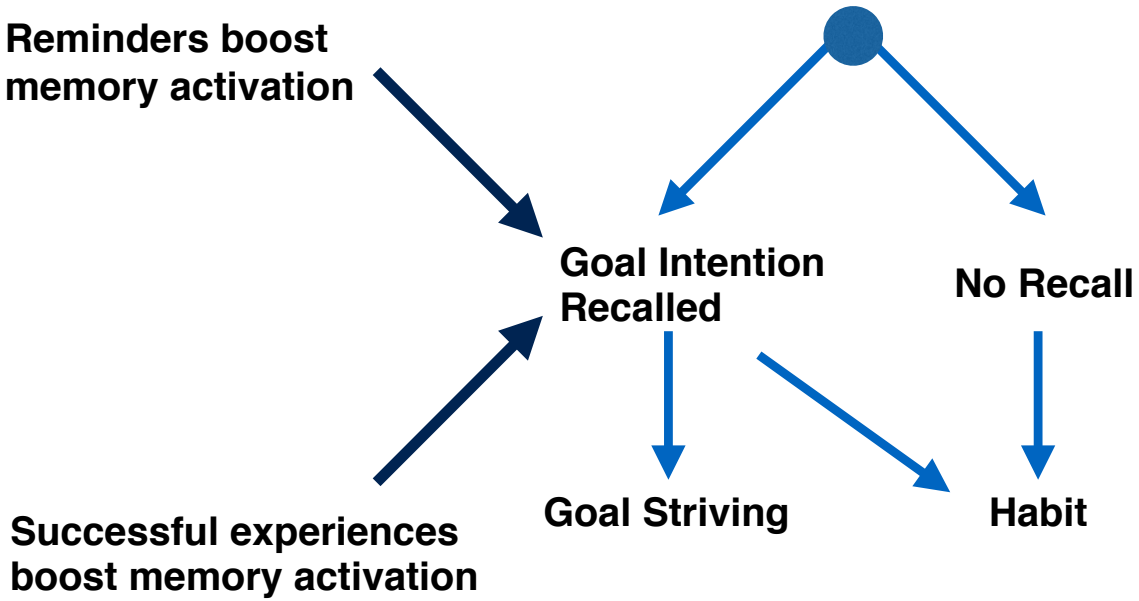
- **Utility learning**: New habits are rewarded and slowly come to dominate over the old habits

ACT-R is Dual-system Theory of Habit Formation

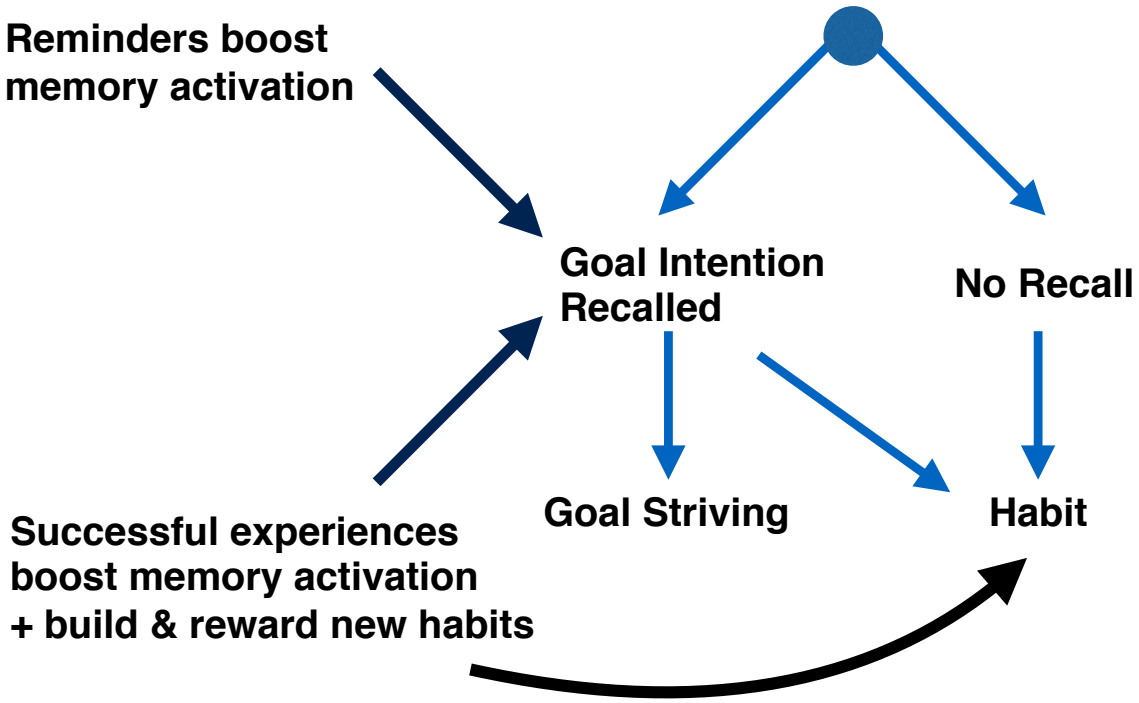


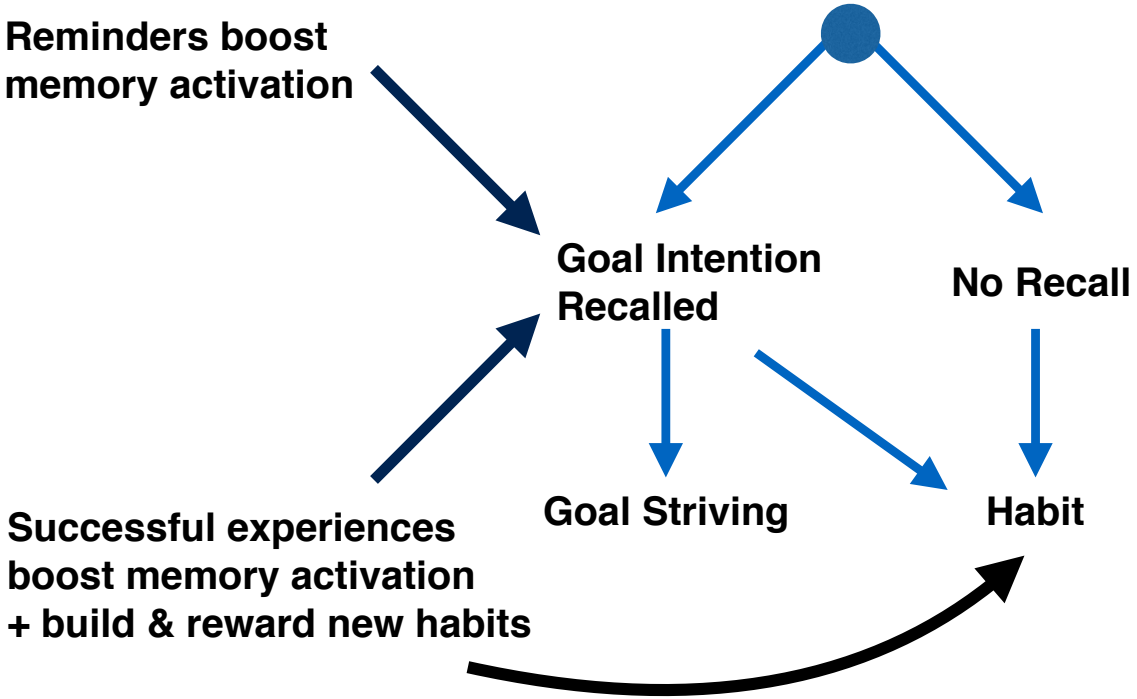
- Systems
  - **Goal striving** (deliberate, effortful) is affected by manipulations of implementation intentions
  - **Habit formation** and habit execution (automatic, mindless) is affected by repeated performance
- From ACT-R we can develop and fit a non-linear probabilistic model that captures the effects of every reminder, every performance, on memory, goal activation, habit strength…

ACT-R is Dual-system Theory of Habit Formation



ACT-R is Dual-system Theory of Habit Formation

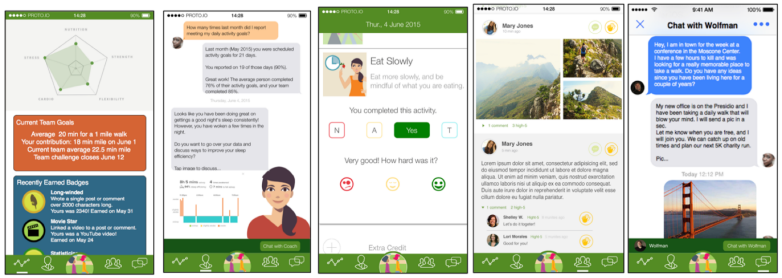




Number	Equation	Summary
(1)	$Pr\,(Success) = Pr\,(G)\,[Pr\,(S) + Pr\,(H_1)\,] + [1 - Pr\,(G)\,]Pr\,(H_2)$	Probability of goal success
(2)	$Success(t) = G(t)[S(t) + H_1(t)] + [1 - G(t)]H_2(t)$	Goal success dynamics
(3)	$G(t) = \frac{exp\,(\beta_0+\beta_1 A_{II}(t)+\beta_2 A_A(t))}{1+exp\,(\beta_0+\beta_1 A_{II}(t)+\beta_2 A_A(t))}$	Probability of recall based on activation level
(4)	$S(t) = \frac{exp\,(U_S(t))}{exp(U_\theta(t))+exp(U_S(t))+exp(U_h(t))}$	Choice probability for goal-striving
(5)	$U_S(t) = \beta_3 + \beta_4 A_{II}(t) + \beta_5 A_A(t),$	Utility of goal-striving
(6)	$U_H(t) = U_H(t-1) + \alpha[R - U_H(t-1)]$	Utility of performing habit
(7)	$H_1(t) = \frac{\exp\,(U_H(t))}{\exp(U_\theta(t))+\exp(U_S(t))+\exp\,(U_H(t))}$	Choice probability of habit competing with goal-striving
(8)	$H_2(t) = \frac{\exp\,(U_H(t))}{\exp(U_\theta(t))+\exp\,(U_H(t))}$	Choice probability of habit when no goal recalled
(9)	$m_n(t_1 \cdots t_n) = \ln\,(\sum_{i=1}^{n}(t_n - t_i)^{-d_i})$	Total base-level activation for reminders and experiences
(10)	$d_i = c\exp(m_{i-1}) + a$	Memory decay as a function of current activation
(11)	$A_{II}(t) = m_n(r_1^+ \cdots r_k^+)$	Base-level learning for an implementation intention as a function of reminders
(12)	$A_A(t) = m_n(g_1^+ \cdots g_k^+)$	Base-level learning as a function of successful behavior performance

Implementation Intention Experiment

- *N* = 64 participants for 28 days
- Self-selected habits to work on:
  - Eat Slowly, Walk more, Eat more vegetables
- Formulate an implementation intention

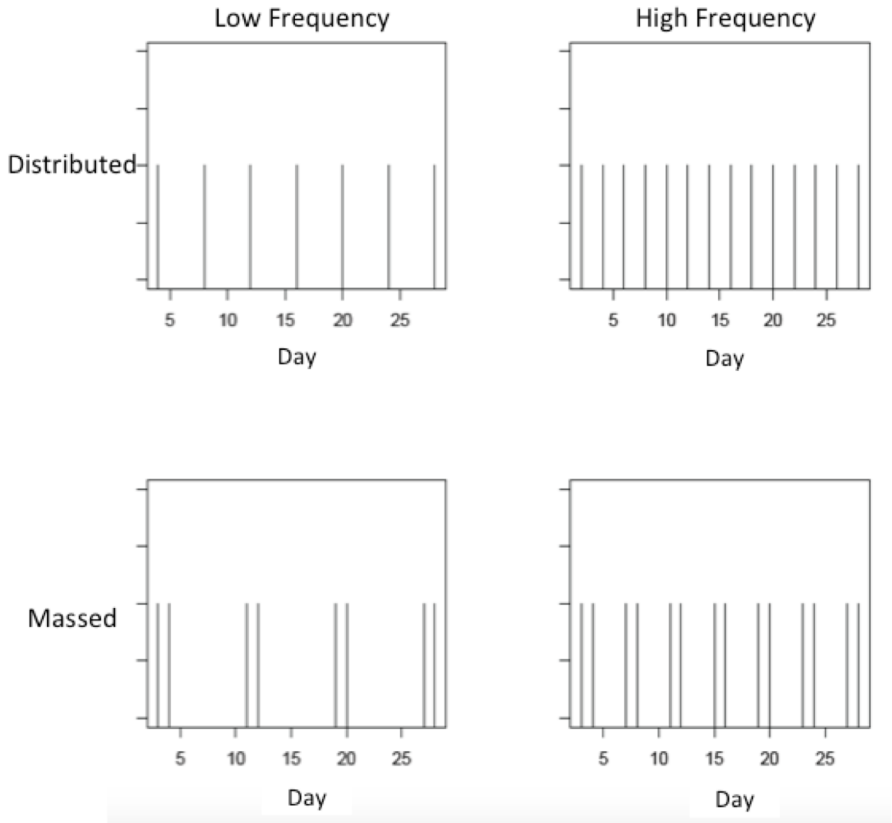


		Self-Efficacy					
		Low			High		
		Reminders			Reminders		
		Presented		Absent	Presented		Absent
		Frequency			Frequency		
		Low	High		Low	High	
Distribution	Distributed	6	7	7	6	7	6
	Massed	6	8		5	6	

Pirolli, P., Mohan, S., Venkatakrishnan, A., Nelson, L., Silva, M., & Springer, A. (2017). Implementation intention and reminder effects on behavior change in a mobile health system: A predictive cognitive model. *Journal of medical Internet research, 19*(11), e397. doi:10.2196/jmir.8217

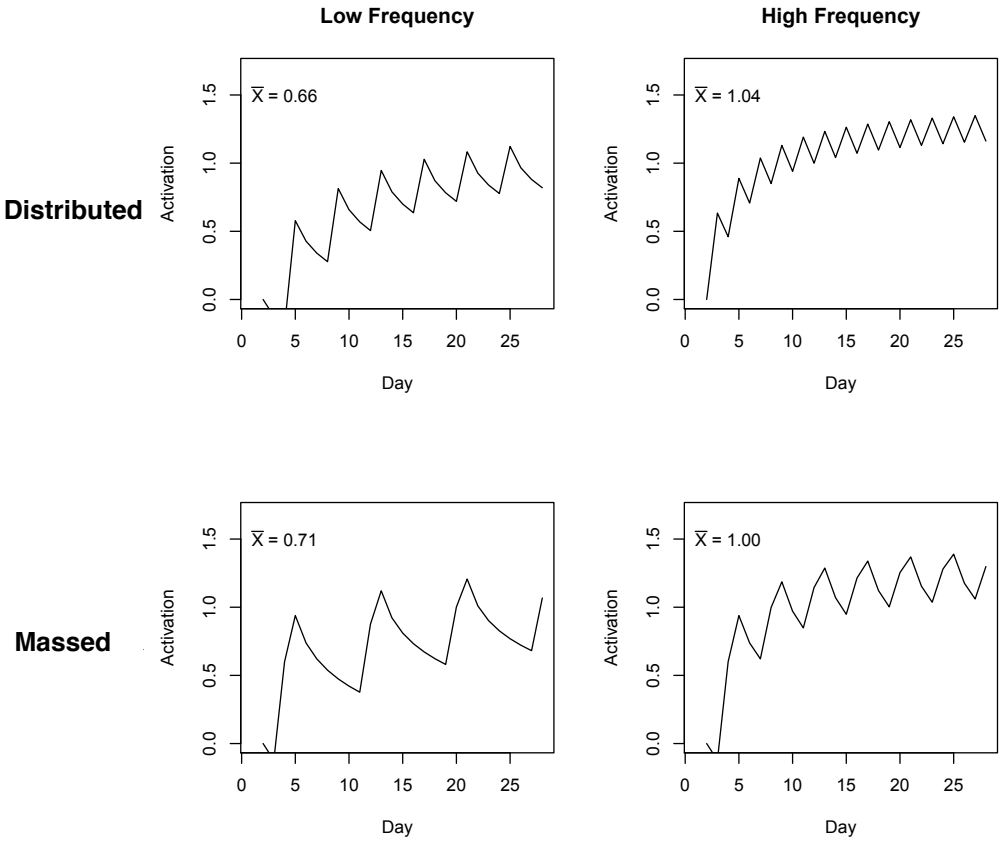
ACT-R Predictions about Different Reminder Schedules for Previously Set Implementation Intentions

Reminder Schedules)



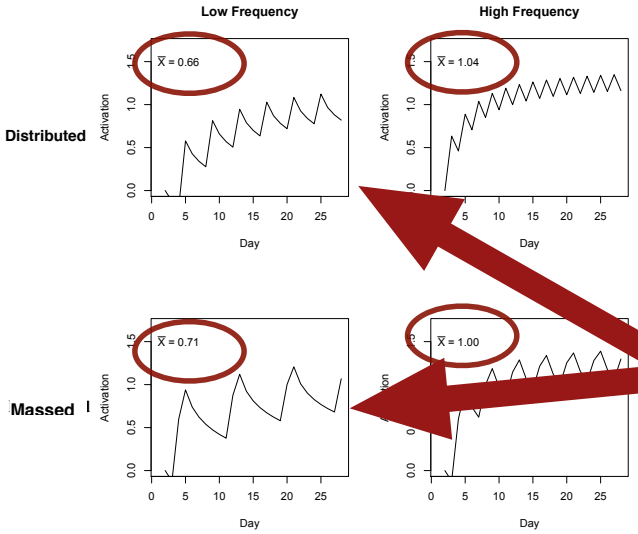
ACT-R Predictions about Different Reminder Schedules for Previously Set Implementations Intentions

Memory Strength of Implementation Intentions



Results

Memory Strength of Implementation Intentions

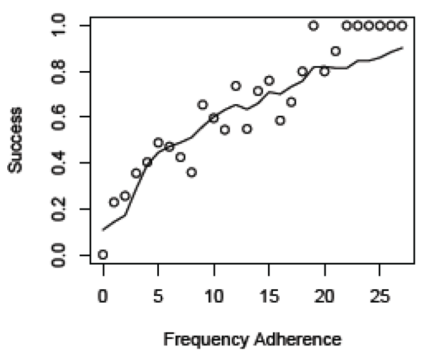


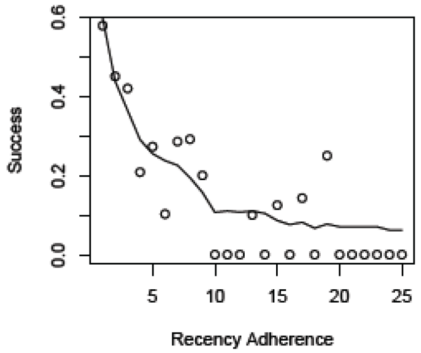
- Order of conditions (high to low) based on how often people achieve their goals:
  - High Frequency/Distributed
  - High Frequency/Massed
  - Low Frequency/Massed
  - Low Frequency/Distributed

ACT-R Model Fit to 28-Day Implementation Intention/Reminder Study

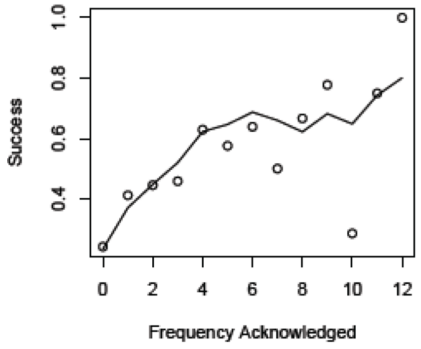
Frequency **Recency**

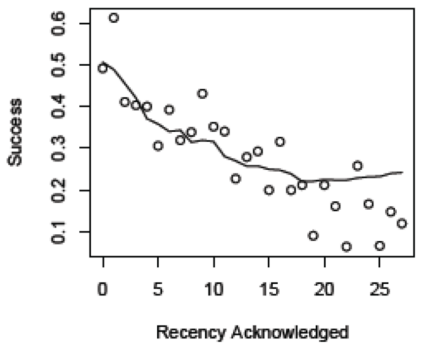
Successful Goal Experiences





Reminders





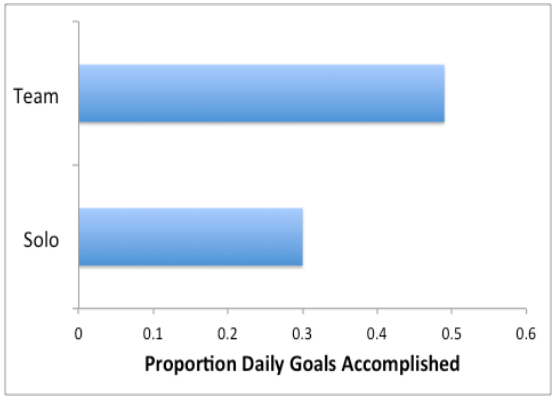
- Fit to individual-level data
- Use ***acknowledged*** reminders (indicates that people actually attended)
- R ***optimx*** error minimization
- ***BFGS*** quasi-Newton method (allows constraints on parameters)

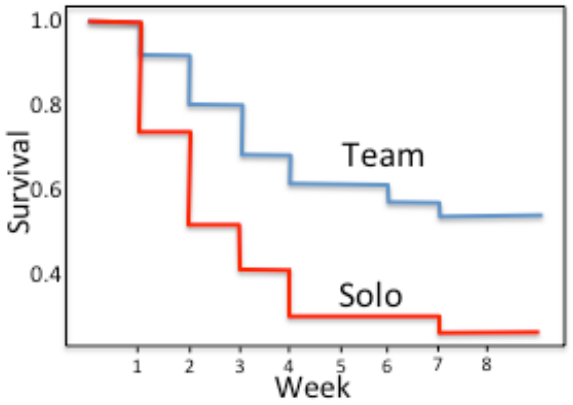
Conclusions & Future Directions

- **Integration/refinement of existing "theory"**
  - ACT-R can provide a start on the unification of behavior change (93 theories, 1765 theoretical constructs….)
    - Goal-Setting Theory, self-efficacy, Attributional Theory of Performance, habit formation
- **New techniques based on cognitive psychology** (?)
  - Implicit attitudes (IAT)/Impicit bias (e.g., towards food/physical activity) , rumination/regret avoidance, preference change….
- **Expand to social**
  - Notable effects of teaming

Teaming

- N = 126 participants in 8 week programs (StessBuster; NutriWalking)
- Physical activity and adherence improve when people are in small teams
- Continued engagement with Little improves with teams (attrition decreases)





Du, H., Venkatakrishnan, A., Youngblood, G. M., Ram, A., & Pirolli, P. (2016). A Group-Based Mobile Application to Increase Adherence in Exercise and Nutrition Programs: A Factorial Design Feasibility Study. *JMIR Mhealth Uhealth, 4*(1), e4. doi:10.2196/mhealth.4900

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  - Implicit attitudes (IAT)/Impicit bias (e.g., towards food/physical activity) , rumination/regret avoidance, preference change….
- **Expand to social**
  - Notable effects of teaming
- **Incorporation into intelligent coaching**
  - Use of mHealth platform for precision behavior medicine
  - Micro-randomized experiments

Fin.

http://www.dianefarrisgallery.com/artist/currelly/ex00/images/uncharted_territory.html

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