DEEP: A Biofeedback Virtual Reality Game for Children At-risk for Anxiety

Marieke van Rooij[a]
m.vanrooij@bsi.ru.nl

Adam Lobel[a]
a.lobel@pwo.ru.nl

Owen Harris
owenllharris@gmail.com

Niki Smit[b]
niki@monobanda.nl

Isabela Granic[a]
i.granic@pwo.ru.nl

[a]Behavioural Science Institute
Radboud University
Nijmegen, the Netherlands

[b]Monobanda Play
Utrecht, the Netherlands

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Abstract
Anxiety disorders are among the most frequently diagnosed mental health problems in children, leading to potentially devastating outcomes on a personal level and high costs for society. Although evidence-based interventions are readily available, their outcomes are often disappointing and variable. In particular, existing interventions are not effective long-term nor tailored to differences in individual responsiveness. We therefore need a new approach to the prevention and treatment of anxiety in children and a commensurate scientific methodology to uncover individual profiles of change. We argue that applied games have a great deal of potential for both. The current paper presents results from a recent pilot study using a biofeedback virtual reality game (DEEP). DEEP integrates established therapeutic principles with an embodied and intuitive learning process towards improved anxiety regulation skills.

Author Keywords
Games for Mental Health; Virtual Reality; Biofeedback; Interventions; Childhood Anxiety

ACM Classification Keywords
H.5.1. Multimedia Information Systems: Artificial, augmented, and virtual realities; J.4. Social and

Virtual Reality Therapy

A key aspect of many evidence-based interventions for anxiety is exposure [e.g., 22, 23, 24]. Exposure is also one of the most common therapeutic techniques that made its way to virtual reality applications. In particular, phobias such as fear of height [e.g., 25, 26] or fear of flying [e.g., 27, 28] are successfully treated using virtual exposure to the particular stress-evoking situations. Additional successful applications of virtual reality exposure are treatments of post-traumatic stress disorder (PTSD) [e.g., 29]. For example, exposing traumatized Vietnam-veterans to flying a virtual helicopter over a virtual Vietnam or a surrounding jungle reduced the amount of reported traumatic feelings [30]. Implementing additional exposure-elements is the next step in developing DEEP as an intervention for children at-risk for anxiety.

Behavioural Sciences: Psychology; K.8.0. Personal Computing: Games

Figure 1: Two DEEP screenshots showing the virtual underwater world (left) and two pictures of children playing DEEP during the pilot study at the 2015 Cinekid Festival Medialab [41].

Anxiety disorders in children

Anxiety disorders are among the most common and highly debilitating mental health illness. In the U.S., up to 32% of children and adolescents are affected by anxiety and about 18% are diagnosed with anxiety disorder [1]. Childhood anxiety is associated with a host of future problems, such as substance abuse, academic failure, risky sexual behaviours, and suicidal behaviour [2]. The impact of anxiety disorders is enormous, both on a personal level and in terms of the associated costs for society as a whole [3]. Clearly, effective prevention and treatment programs are urgently mandated but despite evidence-based psychological therapies being readily available, their outcomes are often disappointing and variable [4]. In particular, existing interventions are not effective over the long-term nor tailored to differences in individual responsiveness [5,6]. Furthermore, a serious barrier in conventional intervention techniques has been to engage people long enough to learn anxiety regulation skills, especially children [7].

Altogether, we need a new approach to the prevention and treatment of anxiety in children and a commensurate scientific methodology to uncover individual profiles of change. Here, we present the in-game data and initial results of a pilot study investigating the potential of a biofeedback virtual reality game (DEEP) as an intervention for anxiety in children.

Anxiety regulation through breathing

A key causal factor that contributes to anxiety disorders in children is *physiological reactivity*. Physiological reactivity is the body's response to a stressor, as indicated for example by changes in heart rate and breathing [8,9]. Anxious children are characterized by hyper-arousal in response to stressors [10] and tend to avoid rather than confront them [11]. In contrast, *physiological regulation* refers to the capacity to regulate, or dampen arousal levels [12]. Breathing, one of the most fundamental physiological functions of the human body, is an integral component of physiological regulation [13]. Specifically, *diaphragmatic breathing* is a well-validated technique to help people relieve stress and tension [14, 15]. Relaxation and breathing exercises teaching people to breath slowly and steadily through their diaphragm are at the heart of many evidence-based psychological therapies for anxiety [e.g., 16, 17, 18].

Using In-game Data

One of the most-compelling reasons to use interactive technologies such as games to promote behavioral change is the possibility to measure human behavior at much smaller time-scales than is common within the behavioral sciences. For example, DEEP samples players' diaphragm expansion at 60 Hz., which is of microscopic precision compared to e.g., observational data from therapy sessions. This in turn, makes in-game data very suitable for (nonlinear) analysis of the patterns of change that underlie global behavioral change. Here, we adopt a *dynamical systems theory* (DST) framework, the mathematical understanding of change and stability in dynamical systems.

DEEP: A virtual reality biofeedback breathing game

DEEP is a virtual reality (VR) game that situates players in a beautiful underwater fantasy world in which they can move around freely and explore at their leisure (see Figure 1; [19,20]). DEEP's main aim is to provide an immersive and relaxing experience; there are no explicit tasks or goals for the players to attain. Moreover, DEEP provides personal breathing and meditation support by promoting diaphragmatic breathing through *biofeedback* [21]. Players' diaphragm expansions are recorded (using a variable resistor/stretch sensor) and directly fed back into the game. As the player inhales properly, her diaphragm expands and the sensor resistance decreases. A microcontroller interprets the sensor readings and sends the data to the game where it is used in gameplay in a number of ways. First, players are instantly informed of the state of their breathing by an expanding and contracting circle before them (see Figure 2).

Figure 2: Two screenshots of DEEP illustrating the way players' breathing is visualised. The large circle to the left corresponds with an inhalation peak; the small circle on the right corresponds with an exhalation peak.

Second, if the player's lungs are at 50% capacity or less, gravity is applied. Third, the direction of breathing (i.e., inhaling versus exhaling) determines the direction and magnitude of force with which the player moves. When the player inhales, an upward force is applied, when the player is above the ground, a forward force is applied, and when the player exhales, an extra forward force is applied. Altogether, slow and deep breathing allows players to move better in the game thus providing en embodied and powerful motivation for diaphragmatic breathing.

Motivation and hypotheses

We believe DEEP has great potential as a possible intervention for anxiety in children: First, in contrast to standard ways of learning anxiety-regulation skills (e.g., through breathing or relaxation exercises), DEEP provides an immersive experience that is much easier to adhere to long-term, especially for children [7]. Second, the use of biofeedback and VR allows for embodiment of the learning process, which is known to improve retention of new skills [31]. Third, DEEP provides exposure to anxiety-inducing situations such as dark spaces and caves. Fourth, DEEP provides insight in players' behaviour at a very fine-grained timescale, which has not been possible with conventional behavioural measures ([32], for more details on quantifying in-game dynamics, see side bar). Altogether, DEEP contains several evidence-based elements that have been shown to successfully reduce anxiety and does so in an immersive, inspiring game that captures children's delight and curiosity. For the current study, we hypothesized that playing DEEP would reduce state-anxiety levels, increase positive affect and decrease negative affect. Furthermore, we were interested in uncovering individual profiles of learning of diaphragmatic breathing by measuring in-game diaphragm expansion and test for catastrophe flags (see side bar).

Dynamical Systems Theory (DST)

DST has gained traction among developmental researchers [e.g., 33, 34, 35]. A crucial DST finding is that behavioral change is often nonlinear and accompanied by *catastrophe flags,* dynamical markers of change that can be detected empirically [32, 36, see e.g., 37, 38, 39, 40 for empirical work]. One of our long-term objectives is to use automated detection of these markers to uncover individual profiles of change in learning diaphragmatic breathing skills. From this, we aim to develop a monitoring system that incorporates real-time in-game information to dynamically adjust the game environment to individual learning trajectories. For example, by becoming less challenging when breathing is stable but shallow or shifting to more challenging context when breathing stabilises after a nonlinear transition into diaphragmatic breathing.

Pilot study at Cinekid

We conducted a pilot study at the Cinekid Medialab, a large multimedia exhibition for children [41]. A total of 86 children between 8-12 years old (M = 10.1, SD = 1.4), 39% girls, 51% boys, played DEEP for 7 minutes. The particular length of play was motivated by previous experience that when given unlimited time, children in this age-group would play DEEP for at least this long. Participants were seated in a comfortable egg-shaped swivelling chair (see Figure 1) on a platform that was not accessible for others besides the players and experimenters. Before and after playing DEEP, we measured self-reported state-anxiety (using the State-Trait Anxiety Inventory for Children, STAIC [42]), and self-reported positive and negative affect (using the Positive and Negative Affect Schedule, PANAS [43]). While children played DEEP, we collected players' diaphragm expansions sampled at 60 Hz. Qualitative observations of players' behaviour, breathing, and important events in the game were also collected. After participating in our experiment, children were asked to rate on a 7-point Likert-scale how much their experience of playing DEEP was described by the following terms: relaxing, great, boring, and whether they felt pressured during playing (adapted from the Intrinsic Motivation Inventory (IMI), [44]).

Experience rating

Figure 3 displays the results of the experience rating, which were overwhelmingly positive. Moreover, importantly for the VR context, the vast majority of children (84%) reported no signs of nausea at all, suggesting DEEP is much more accessible and feasible to implement compared to many VR designs [45].

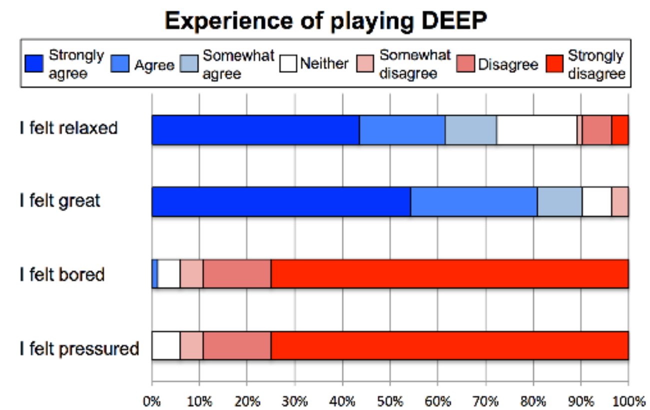

Figure 3: Experience rating of playing DEEP during pilot study.

DEEP's effect on anxiety and affect

Comparing players' self-reported state-anxiety before and after playing DEEP for only seven minutes, resulted in a significant decrease in self-reported state-anxiety, $t(85) = 2.02$, $p = .046$. This confirms our hypothesis and suggests that DEEP could indeed be an effective intervention for children at-risk for anxiety disorders. Unexpectedly, comparing positive affect (PA) and negative affect (NA) ratings before and after playing DEEP did not result in any significant differences (PA: $t(85) = .25$, $p = .805$; NA: $t(85) = -.20$, $p = .841$). This may be explained by the larger context in which the DEEP pilot experiment was embedded. The Medialab is an exciting and fun place and our participants may have already been experiencing low (high) levels of negative (positive) affect. Indeed, NA scores were relatively close to the minimum (M = 13.0, SD = 4.4, min. = 5.0). PA scores on the other hand were similar to baseline values [46], (M = 36.4, SD = 7.5, max. = 50.0).

Breathing patterns

Figure 4 displays the diaphragm expansion recorded for twelve randomly selected participants. There are large qualitative differences between the signals, suggesting a strong idiosyncrasy among individual players in the way they respond to DEEP. In order to gain more insight into the relationship between these patterns and players' responsiveness, we compared diaphragm expansion patterns with experimenter observations.

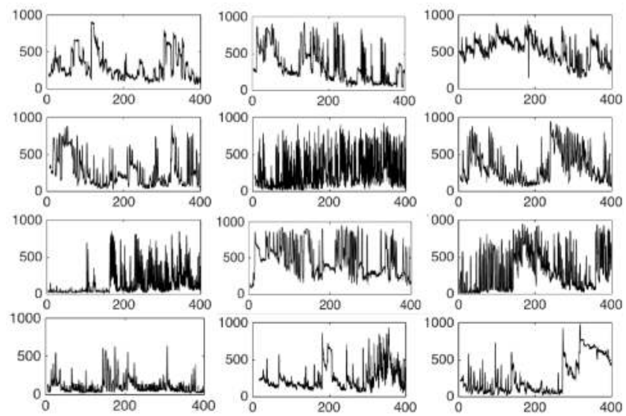

Figure 4: Breathing data (sampled at 60 Hz., 400 samples equals 6 minutes and 40 seconds) of twelve randomly selected participants.

Figure 5 displays three examples demonstrating the match between characteristic diaphragm expansion patterns and the observed breathing quality and behaviour of the players. Particularly interesting is the middle panel; this player quite suddenly transitioned into diaphragmatic breathing during gameplay, which is exactly what we would hope to see when using DEEP as an intervention for anxiety.

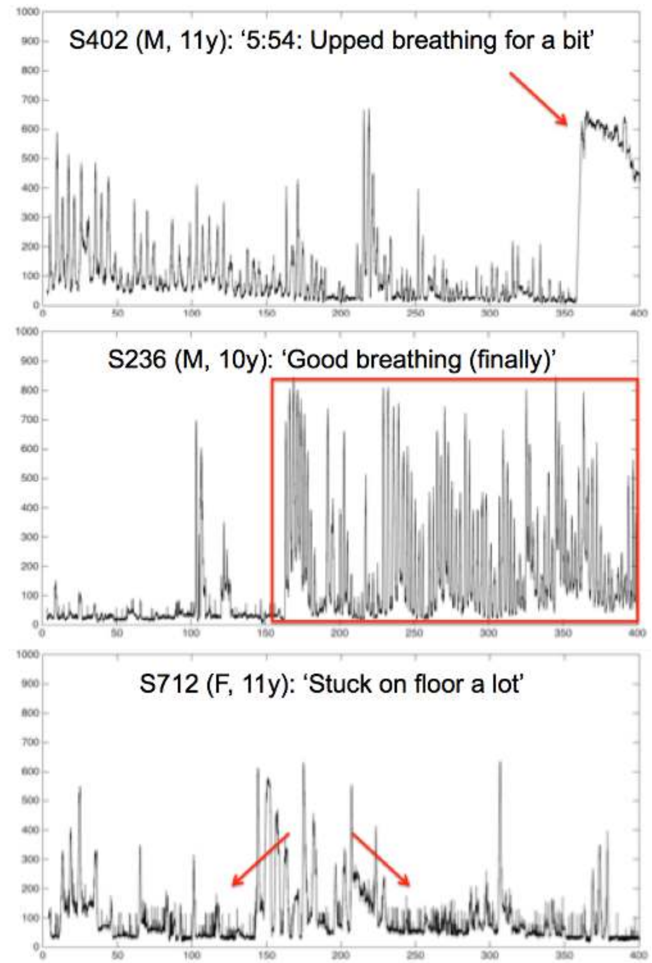

Figure 5: Diaphragm expansion signals of three participants combined with the qualitative assessments of the experimenter demonstrating the match between quantitative and qualitative breathing quality and behavior.

Furthermore, this transition seems to be anticipated by a short peak in variability just seconds before. This suggests that qualitative changes in breathing may indeed be anticipated by catastrophe flags.

Future research

Results of the pilot study demonstrated that playing DEEP reduces state-levels of anxiety in children and thus confirmed its potential as an intervention for anxiety. However, additional research is warranted. Specifically, we are planning to replicate current findings in a controlled laboratory setting and include cognitive performance outcome measures as well (e.g., automatic processing [47] and working memory [48]). Additionally, we aim to gain more insight into the effect of exposure-elements in DEEP and finding ways to strengthen this effect.

With respect to the in-game breathing data, we are currently investigating the possibility of segmentation. Preliminary analysis of the diaphragm expansion and observational data suggest that there may be four qualitatively different individual profiles; 1) players that are new to diaphragmatic breathing and do not develop the skill through playing DEEP (e.g., Figure 5, lower panel), 2) players that are new to diaphragmatic breathing and who display a sudden transition into it (e.g., Figure 5, middle panel), 3) players that are new to diaphragmatic breathing and who display a gradual transition into the new skill, and 4) players that already understand diaphragmatic breathing. Further analysis is required to confirm these characterisations and to find a suitable segmentation. Furthermore, we aim to investigate the presence and possibility of automated detection of catastrophe flags, dynamical markers predictive of change [32, 36].

Ultimately, we aim to characterise individual breathing patterns in real-time in order to dynamically-adapt the virtual environment to each individual player's needs. We expect that tailoring DEEP this way and incorporating DEEP into existing (e.g. cognitive behavioural therapy) interventions will significantly push effect sizes and help reduce anxiety in children.

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References

1. Kathleen R. Merikangas, Jian-ping He, Marcy Burstein, Sonja A. Swanson, Shelli Avenevoli, Lihong Cui, Corina Benjet, Katholiki Georgiades, and Joel Swendsen. 2010. Lifetime prevalence of mental disorders in US adolescents: results from the National Comorbidity Survey Replication–Adolescent Supplement (NCS-A). *Journal of the American Academy of Child & Adolescent Psychiatry* 49, 10: 980-989.
2. Lianne J. Woodward and David M. Fergusson. 2001. Life course outcomes of young people with anxiety disorders in adolescence. *Journal of the American Academy of Child & Adolescent Psychiatry* 40, 9: 1086-1093.
3. Paul E. Greenberg, Tamar Sisitsky, Ronald C. Kessler, Stan N. Finkelstein, Ernst R. Berndt, Jonathan RT Davidson, James C. Ballenger, and Abby J. Fyer. 1999. The economic burden of anxiety disorders in the 1990s. *Journal of Clinical Psychiatry* 60: 427–435.
4. Shirley Reynolds, Charlotte Wilson, Joanne Austin, and Lee Hooper. 2012. Effects of psychotherapy for

anxiety in children and adolescents: A meta-analytic review. *Clinical psychology review* 32, 4: 251-262.

5. Anthony C. James , Georgina James, Felicity A. Cowdrey, Angela Soler, and Aislinn Choke. 2013. Cognitive behavioural therapy for anxiety disorders in children and adolescents. *Cochrane Database Syst Rev* 6.
6. Sam Cartwright-Hatton, Chris Roberts, Prathiba Chitsabesan, Claire Fothergill, and Richard Harrington. 2004. Systematic review of the efficacy of cognitive behaviour therapies for childhood and adolescent anxiety disorders. *British journal of clinical psychology* 43, 4: 421-436.
7. Marc S. Karver, Jessica B. Handelsman, Sherecce Fields, and Len Bickman. 2006. Meta-analysis of therapeutic relationship variables in youth and family therapy: The evidence for different relationship variables in the child and adolescent treatment outcome literature. *Clinical psychology review* 26, 1: 50-65.
8. Aaron Antonovsky,. 1979. *Health, stress, and coping.*
9. Paul Grossman. 1983. Respiration, stress, and cardiovascular function. *Psychophysiology* 20, 3: 284-300.
10. Carl F. Weems, Alan H. Zakem, Natalie M. Costa, Melinda F. Cannon, and Sarah E. Watts. 2005. Physiological response and childhood anxiety: Association with symptoms of anxiety disorders and cognitive bias. *Journal of Clinical Child and Adolescent Psychology* 34, 4: 712-723.
11. Tal Carthy, Netta Horesh, Alan Apter, and James J. Gross. 2010. Patterns of emotional reactivity and regulation in children with anxiety disorders. *Journal of Psychopathology and Behavioral Assessment* 32, 1: 23-36.
12. Barry R. Dworkin. 1993. *Learning and physiological regulation*. University of Chicago Press.
13. A. D. Craig. 2008. Interoception and emotion: a neuroanatomical perspective. *Handbook of emotions*, *3*: 272-88.
14. Robert Fried and Joseph Grimaldi. 1993. *The Psychology and Physiology of Breathing: In Behavioral Medicine, Clinical Psychology and Psychiatry*. Springer Science & Business Media.
15. Rolf Sovik. 2000. The science of breathing–the yogic view. *Progress in brain research,* 122: 491–505.
16. Philip C. Kendall. 1994. Treating anxiety disorders in children: results of a randomized clinical trial. Journal of consulting and clinical psychology, 62, 1: 100.
17. Philip C. Kendall, Ellen Flannery-Schroeder, Susan M. Panichelli-Mindel, Michael Southam-Gerow, Aude Henin, and Melissa Warman. 1997. Therapy for youths with anxiety disorders: A second randomized clinical trial. *Journal of consulting and clinical psychology* 65, 3: 366.
18. Wendy K. Silverman, Armando A. Pina, and Chockalingam Viswesvaran. 2008. Evidence-based psychosocial treatments for phobic and anxiety disorders in children and adolescents. *Journal of Clinical Child & Adolescent Psychology* 37, 1: 105-130.
19. Owen L. L. Harris. 2015. *owenllharris.com/deep.* Retrieved from http://owenllharris.com/deep
20. Niki Smit. 2015. *DEEP*. Retrieved from http://www.monobanda-play.com/project/deep
21. Owen L. L. Harris. 2015. DEEP breathing in virtual reality, TEDxBratislava. Video. (4 July2015). Retrieved from https://www.youtube.com/watch?v=EYkWghdLNJM
22. Susan Mineka and Cannon Thomas. 1999. *Mechanisms of change in exposure therapy for anxiety disorders.*

23. Richard J. McNally. 2007. Mechanisms of exposure therapy: How neuroscience can improve psychological treatments for anxiety disorders. *Clinical psychology review* 27, 6: 750-759.

24. Steven L. Berman, Carl F. Weems, Wendy K. Silverman, and William M. Kurtines. 2000. Predictors of outcome in exposure-based cognitive and behavioral treatments for phobic and anxiety disorders in children. *Behavior Therapy* 31, 4: 713-731.

25. Dan Opdyke, James S. Williford, and Max North. 1995. Effectiveness of computer-generated (virtual reality) graded exposure in the treatment of acrophobia. *American Journal of Psychiatry* 1, 152: 626-28.

26. P. M. G. Emmelkamp, M. Krijn, A. M. Hulsbosch, S. De Vries, M. J. Schuemie, and C. A. P. G. Van der Mast. 2002. Virtual reality treatment versus exposure in vivo: a comparative evaluation in acrophobia. *Behaviour research and therapy* 40, 5: 509-516.

27. Barbara O. Rothbaum, Larry Hodges, Benjamin A. Watson, G. Drew Kessler, and Dan Opdyke. 1996. Virtual reality exposure therapy in the treatment of fear of flying: A case report. *Behaviour Research and Therapy* 34, 5: 477-481.

28. Barbara O. Rothbaum, Larry Hodges, Samantha Smith, Jeong Hwan Lee, and Larry Price. 2000. A controlled study of virtual reality exposure therapy for the fear of flying. *Journal of consulting and Clinical Psychology* 68, 6: 1020.

29. Joann Difede and Hunter G. Hoffman. 2002. Virtual reality exposure therapy for World Trade Center post-traumatic stress disorder: A case report. *Cyberpsychology & Behavior* 5, 6: 529-535.

30. Barbara O. Rothbaum, Larry F. Hodges, David Ready, Ken Graap, and Renato D. Alarcon. 2001. Virtual reality exposure therapy for Vietnam veterans with posttraumatic stress disorder. *Journal of Clinical Psychiatry* 62, 8: 617-622

31. Arthur M. Glenberg. 2008. Embodiment for education. In *Handbook of cognitive science: An embodied approach*, Paco Calvo and Toni Gomila (Eds.), Elsevier, Amsterdam, 355-372.

32. J. A. Scott Kelso. 1997. *Dynamic patterns: The self-organization of brain and behavior*. MIT press.

33. Esther Thelen, Linda B. Smith, Annette Karmiloff-Smith, and Mark H. Johnson. 1994. A dynamic systems approach to the development of cognition and action. *Nature* 372, 6501: 53-53.

34. Paul van Geert. 1994. *Dynamic systems of development: Change between complexity and chaos*. Harvester Wheatsheaf.

35. Marc D. Lewis. 2000. The promise of dynamic systems approaches for an integrated account of human development. *Child development*: 36-43.

36. C. A. Isnard and E. Christopher Zeeman. 1976. Some models from catastrophe theory in the social sciences. *The Use of Models in the Social Sciences. Tavistock, London, UK*.

37. Paula Fitzpatrick, Claudia Carello, Richard C. Schmidt, and David Corey. 1994. Haptic and visual perception of an affordance for upright posture. *Ecological Psychology* 6, 4: 265-287.

38. Betty Tuller, Pamela Case, Mingzhou Ding, and J. A. Scott Kelso. 1994. The nonlinear dynamics of speech categorization. *Journal of Experimental Psychology: Human perception and performance* 20, 1: 3.

39. Damian G. Stephen, Rebecca A. Boncoddo, James S. Magnuson, and James A. Dixon. 2009. The dynamics of insight: Mathematical discovery as a phase transition. *Memory & Cognition* 37, 8: 1132-1149.

40. Marieke M. J. W. van Rooij. 2013. *What Changes When We Change Our Decision Strategy? A*

Dynamical Account of Transitions between Risk-averse and Risk-seeking Choice Behavior. Ph.D. dissertation, University of Cincinnati, Cincinnati, OH.

41. MEDIALAB. 2015. Retrieved from http://www.cinekid.nl/festival/medialab1
42. Charles D. Spielberger. 1973. *Manual for the State-Trait Anxiety Inventory for Children*. Palo Alto, CA: Consulting Psychologist Press.
43. David Watson, Lee A. Clark, and Auke Tellegen. 1988. Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of personality and social psychology* 54, 6: 1063.
44. Edward L. Deci and Richard M. Ryan. 2003. Intrinsic motivation inventory. *Self-Determination Theory*.
45. Albert Rizzo and Gerard Jounghyun Kim. 2005. A SWOT analysis of the field of virtual reality rehabilitation and therapy. *Presence* 14, 2: 119-146.
46. Jeff Laurent, Salvatore J. Catanzaro, Thomas E. Joiner Jr., Karen D. Rudolph, Kirsten I. Potter, Sharon Lambert, Lori Osborne, and Tamara Gathright. 1999. A measure of positive and negative affect for children: scale development and preliminary validation. *Psychological assessment* 11 3: 326.
47. J. Ridley Stroop. 1935. Studies of interference in serial verbal reactions. *Journal of experimental psychology* 18, 6: 643.
48. Alan Baddeley. 2003. Working memory: looking back and looking forward. *Nature reviews neuroscience* 4, 10: 829-839.