UNIVERSITY OF CALIFORNIA, IRVINE

The Psychological and Physiological Effects of Experimentally Induced Smiling During Physical and Social Pain

DISSERTATION

To be submitted in partial satisfaction of the requirements for the degree of

DOCTOR OF PHILOSOPHY

In Psychological Science

by

Marie P. Cross, M.A.

Dissertation Committee:
Associate Professor Sarah D. Pressman, Chair
Associate Professor Belinda Campos
Professor Peter H. Ditto

2019

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ACKNOWLEDGMENTS

"In the end, though, maybe we must all give up trying to pay back the people in this world who sustain our lives. In the end, maybe it's wiser to surrender before the miraculous scope of human generosity to just keep saying thank you, forever and sincerely, for as long as we have voices."
~Elizabeth Gilbert

I have had the incredible fortune of being surrounded by an inspirational team of mentors, friends, and family, who have helped me grow in so many different ways over the course of my graduate school journey.

Sarah, I knew from the moment I met you that you were the perfect advisor match. I learned so much from you over our time together, such as how to ask deep questions and design experiments in order to answer them, how to be an effective collaborator, and how to manage my time against the pressures of graduate school. I also learned incredibly important things like the definition of rick-rolling, the importance of having meetings outside, and how to have meaningful conference experiences that involve planking competitions. No matter what happened, I knew you were always in my corner. Your energy and positivity are infectious, and I'm pretty sure if we were left to our own devices outside time constraints, we would talk together non-stop for hours on end about everything under the sun. No matter where my career takes me, I know I can count on you as my lifelong mentor and friend (now Facebook official!).

Pete and Belinda, thank you so much for taking the time to help make this project the best that it could be. Your support over my time in graduate school has meant so much to me, and I am honored to have had you as my mentors. Roxy and Karen, thank you for your words of wisdom every step of the way. Julian, even though I only saw you a few times a year, you always made me feel like I was one of your own students. Thank you for your enthusiasm in my research and my academic career, and for helping me feel like I belong in the world of academia.

Jennie, Nicolette, Celina, and Diane, your yoga classes were a beautiful respite from the swirling chaos of graduate school. Through your loving teaching, I was constantly reminded that I am enough exactly as I am, wisdom I hope to carry with me throughout my career and pass on to my future students.

Susan, Aline, Tina, Grace, and Lily, I am so thankful to have had you as my dissertation study managers. You decreased my stress levels on a daily basis and I am honored to have had the opportunity to work with such intelligent and driven women. I would also like to thank my teams of undergraduate research assistants, who put in countless hours to help me finish these research projects.

I have had the opportunity to meet some of the most incredible graduate students at UCI who have become my collaborators and friends. To my cohort, Stephanie, Frank, Jason, Lauren, Rachel, Becky, Karina, Adam, Brooke, Nicky, and Amanda, I knew from our early games of fish bowl that we would spend a large part of this wild and crazy ride making each other laugh. Thank you so much for your support, including but not limited to late night statistics study sessions, proofreading NSF essays, and rocking the dance floor.

Lauren, my fellow wine and cheese connoisseur, thank you for always helping me put things into perspective. I have always been impressed with your work-life balance, how resilient of a person you are, and how well you know yourself and what makes you happy. Whenever anything went wrong, I knew that you would find a way to reassure me. I am so thankful that we have been able to stay long distance friends and that I get to hear your incredible laugh so often!

Nicky, you did something that no one else has been able to do – you made me feel comfortable with statistics. I was so overwhelmed by statistics classes our first year, and you generously gave up your time to make sure I knew what was going on. Thank you for answering all of my questions over the years, and never making me feel stupid in the process. You are such a warm and loving presence – I'm so thankful to call you my friend.

Becca, Emily, Sean, and Kevin, you made me feel welcome at UCI from the second I walked on to campus. Thank you for the wonderful memories, including the wide variety of karaoke songs, Backstreet Boys and Britney Spears concerts, board game nights, and getting *so* close to a softball championship!

I am so thankful that I shared an office with five kindred spirits who have served as inspirational role models: Emily, Brooke, Johnny, Desi, and Amanda. Emily, thank you so much for your guidance, especially during my first year when I had absolutely no idea what was going on. Brooke, you helped crush my imposter syndrome with your never-ending encouragement. I'm always amazed at how you manage to give such valuable feedback in such an uplifting manner. Thank you for your positivity and for always believing in me. Johnny, I have no idea what I would have done without your zen presence in my life. No matter what nonsense stressful thing I was worried about, I always felt better after talking with you. Also, thank you for talking sports with me and for helping me survive my first (and hopefully, all future) fantasy football seasons. Desi, you are living proof that superhumans exist. Your connection with your intuition is astounding – thank you for your friendship and for imparting so much wisdom to me over the years. Amanda, my undercover friend! How would I have survived this journey without you? I probably still would have no idea how to pour a beer today if you didn't exist in my life. You are one of the strongest, most resilient people I have ever met. From Barcelona to Pismo Beach to Victoria, I hope we continue to explore the world and live life to its fullest, beginning with our new conquest, the east coast!

Thank you to my friends who witnessed this process begin even before I started graduate school. Kate, I still can't believe that we've been friends for over 20 years. Even though we haven't lived in the same city for a long time, you always find ways to support me from afar. Isabella, my best foodie friend, thank you for encouraging that our hangouts always revolve around the delicious experience of eating, whether from a cooler or at a restaurant. Robert, thank you for bringing Mario Party back in my life during a crucial time and putting up with my competitiveness. Kelly, I am so thankful that we got to live in the same state again, at least for a little while. We were able to stay friends with a whole country in between us, and I absolutely believe that we can do that again. Thank you for gushing about travel with me – I can't wait for all of our future trips together!

Sneha, my only-a-little-bit-but-not-too-much-nature, let's-just-order-both, it's-not-so-bad-we'll-just-move-to-London best friend. Thank you for being the person I call after a good day, a bad day, or an in-between day. You have been with me during every single step of this process, from my adjustment to graduate school to my dissertation writing frustrations. You are such a role model to me - you infect everyone around you with happiness and donate so much of your time toward helping other people. Thank you for knowing how to instantaneously make me laugh and always putting a positive spin on whatever is bothering me. You really ARE Ted's two best friends!

My family has supported me through every step of this journey. Aunt Karen, Christopher, Patrick, James, and Aunt Debra, thank you for not kicking me out of family reunions when I started talking about yet another health psychology topic. Bethany, I am so thankful we got to overlap for a short while in southern California! I have no idea what I would have done without you to buffer my dissertation stress with beach views, beer, baseball, and Game of Thrones. Grandma, thank you for serving as a role model of what a strong, educated woman can be. Every time I talk with you, I am reminded of what is truly important in life. Grandpa, thank you for surrounding me with family support from the minute I was born. It is because of you that I feel so close and supported by my extended family, and I can never thank you enough. I miss you.

Finally, thank you to David, Mom, and Dad. David, out of everyone in my life, you have always shown the most interest in my research. When I have been burned out and just wanted to throw my laptop out of the window, you somehow managed to reignite my passion for my area of study. Thank you for letting me talk your ear off since, literally, the day you were born. I could not have asked for a more supportive, loving, caring brother than you.

Mom and Dad, thank you for always believing in me and never for a second doubting that I could fulfill my dreams. You taught me that it's not the end result that matters, it's the effort you put in along the way, and I think I have finally internalized that message. Thank you for putting such an emphasis on the importance of education, and for working so hard to ensure that I would have access to an excellent one. Mom, I am so thankful that you are not only my mother but my closest friend. Every book we read out loud together (shout out to *Harry Potter and the Sorcerer's Stone*) or late night of helping me with my homework brought me to where I am today. Whether it's trip planning, drinking wine, or geeking out over the newest medical finding, we definitely know how to have fun! You are, and have always been, my model for an intelligent, hard-working woman in the sciences. I am so proud to call you my science mom! Dad, you always encouraged me to find a career in which I would feel fulfilled. You sparked my passions for both positive psychology and teaching, and taught me all the ins and outs of academia when it was still a world I didn't understand. Thank you for teaching me not how to talk, but how to *speak*. One of the most important lessons I learned from you was that to be an effective instructor, you also need to be an engaging storyteller. You taught me the value of the pause and how to weave stories from other disciplines into the narrative of my classroom. Thank you for serving as a reminder that we are all students of life.

I would also like to thank the American Psychological Association for the Dissertation Research Grant that helped make this project possible.

CURRICULUM VITAE

Marie P. Cross

EDUCATION

Ph.D. **University of California, Irvine,** Health Psychology, 2019
Minor: Quantitative Methods
Dissertation: *The Psychological and Physiological Effects of Experimentally Induced Smiling During Physical and Social Pain*

M.A. **University of California, Irvine,** Social Ecology, 2016
Thesis: *Does a Smile a Day Keep the Doctor Away? The Connections between Facial Expressions in Student Identification Photographs and Health Care Center Visitation*

B.A. **University of California, Los Angeles,** Psychology, 2012
Departmental Honors, *cum laude*
Phi Beta Kappa

PUBLICATIONS

**Denotes an undergraduate student I directly supervised in research*

Urban, E. J., Cochran, K. J., Acevedo, A. M., **Cross, M. P.,** Pressman, S. D., & Loftus, E. F. (2019). Misremembering pain: A memory blindness approach to adding a better end. *Memory & Cognition.* doi.org/10.3758/s13421-019-00913-9

Cross, M. P. & Pressman, S. D. (2018). Say cheese? The connections between positive facial expressions in student identification photographs and health care seeking behavior. *Journal of Health Psychology.* doi:10.1177/1359105318790066

Pressman, S. D. & **Cross, M. P.** (2018). Moving beyond a one-size-fits-all view of positive affect in health research. *Current Directions in Psychological Science.* doi.org/10.1177/0963721418760214

Cross, M. P., *Hofschneider, L., *Grimm, M., & Pressman, S. D. (2018). Subjective well-being and physical health. In E. Diener, S. Oishi, and L. Tay (Eds.), *Handbook of Well-Being.* Salt Lake City, UT: DEF Publishers. doi:nobascholar.com

Jenkins, B. N., Hunter, J. F., **Cross, M. P.,** Acevedo, A. M., & Pressman, S. D. (2018). When is affect variability bad for health? The association between affect variability and immune response to the influenza vaccination. *Journal of Psychosomatic Research, 104,* 41-47. doi:10.1016/j.jpsychores.2017.11.002

Hunter, J., F., **Cross, M. P.,** & Pressman, S. D. (2018). The associations between positive affect and health: Findings and future directions. In C.R. Snyder, S. J. Lopez, L. M. Edwards, and S. C. Marques (Eds.), *The Oxford Handbook of Positive Psychology, 3rd Edition*. doi:10.1093/oxfordhb/9780199396511.013.61

Cross, M. P., & Pressman, S. D. (2017). Understanding the connections between positive affect and health. In C. L. Cooper and J. C. Quick (Eds.), *The Wiley Handbook of Stress and Health: A Guide to Research and Practice.*

Pressman, S. D., Kraft, T. L., & **Cross, M. P.** (2015). It's good to do good and receive good: The impact of a "pay it forward" style kindness intervention on giver and receiver well-being. *Journal of Positive Psychology, 10*(4), 293-302. doi:10.1080/17439760.2014.965269

Manuscripts Under Review

Cross, M. P., *Gheorma, L., & Pressman, S. D. Contrasting experimentally manipulated and natural smiles. Revise and resubmit. *Frontiers in Emotion Science.*

Manuscripts in Preparation

Cross, M. P., Acevedo, A. M., Leger, K. A., & Pressman. S. D. How and why smiling could influence physical health.

*Smirnova, M., **Cross, M. P.,** McKenna, C., Faraci, D. C., Ditto, P. H., & Pressman, S. D. The effects of smiling on cheating behavior.

Acevedo, A. M., **Cross, M. P.,** Hunter, J. F., Jenkins, B. N., & Pressman, S. D. Calming the pain: The association between specific positive affect subtypes and the pain response.

HONORS AND AWARDS

Dean's Dissertation Writing Fellowship ($12,885) 2019
School of Social Ecology
University of California, Irvine

Outstanding Mentoring Award ($200) 2014, 2015, 2016, 2017, 2019
School of Social Ecology, University of California, Irvine

Carol Kupers Whalen Graduate Research Award ($1,000) 2018
Department of Psychological Science
University of California, Irvine
Awarded to a graduate student who is conducting innovative research on a fundamental question in health psychology and contributes to the department beyond his or her own work

Travel Grant ($400) 2014, 2015, 2018
Associated Graduate Students, University of California, Irvine

Dissertation Research Award ($1,000) 2017
American Psychological Association
Awarded to students whose dissertation research reflects excellence in scientific psychology

Multidisciplinary Design Program ($2,000) 2017
Undergraduate Research Opportunities Program
University of California, Irvine
Awarded to projects that provide an environment for undergraduate students to develop the multidisciplinary skills and knowledge that will propel them into further studies or careers in fields that explore the connections between different disciplines

Dissertation Data Collection Stipend ($1,000) 2017
School of Social Ecology, University of California, Irvine

La Verne Noyes Fellowship ($3,000) 2016
University of California, Irvine
Awarded to an academically superior graduate student who is a direct descendant of a World War I U.S. Navy or Army veteran

Alison Clarke-Stewart Excellence in Research Award ($500) 2015
Department of Psychological Science
University of California, Irvine
Awarded to the graduate student who submitted the best second year project; given to a paper that was creative, original, theoretically and practically strong, and reflected a large amount of independent work by the student

Graduate Research Fellowship Program Honorable Mention 2015
National Science Foundation

TEACHING EXPERIENCE

Instructor at the University of California, Irvine

Mean ratings are from student course evaluations.

Course	Date	Mean Rating	Course Enrollment
Human Stress	Spring 2019	Not yet available	256 students
	Spring 2018	6.11 out of 7	230 students
Health Psychology	Summer 2018	8.5 out of 9	39 students

Teaching Assistant at the University of California, Irvine
Mean ratings are from student course evaluations.

Course	Date	Mean Rating	Course Enrollment
Health Psychology	Fall 2017	5.94 out of 7	369 students
	Spring 2017	6.19 out of 7	341 students
	Winter 2016	5.58 out of 7	349 students
	Spring 2015	6.08 out of 7	388 students
	Fall 2014	5.82 out of 7	356 students
	Winter 2014	6.11 out of 7	367 students
Human Stress	Fall 2018	6.47 out of 7	137 students
	Fall 2013	5.65 out of 7	341 students
Positive Psychology	Fall 2016	6.15 out of 7	252 students
	Spring 2016	6.14 out of 7	284 students
Psychology Fundamentals	Winter 2017	5.63 out of 7	437 students
Naturalistic Field Research	Fall 2015	6.54 out of 7	23 students
Gerontology	Winter 2015	6.26 out of 7	96 students
Environmental Psychology	Spring 2014	5.80 out of 7	386 students

MENTORSHIP

I have worked closely with eight undergraduate honors students. The following are the honors students I have worked with, their current positions, and the awards they won under my mentorship.

Grace Kim (2018-2019)
Current position: Public Health Studies undergraduate student at the University of California, Irvine
Title of honors thesis: *The Connections between Personality Traits and Pain Tolerance*

Jeanne Kim (2018-2019)
Current position: Psychology and Social Behavior undergraduate student at the University of California, Irvine
Title of honors thesis: *The Connections between Anxiety Sensitivity and Pain Tolerance*

Katlyn King (2016-2017)
Current position: Demography and Social Analysis Master's student at the University of California, Irvine
Title of honors thesis: *Facial Attraction and Academic Success: Does Beauty Trump Brains?*
Social Ecology Excellence in Research Distinction (Spring, 2017)
Summer Undergraduate Research Opportunities Program (Summer, 2016; $1,800)

Lauren Hofschneider (2015-2016)

Current position: Health Psychology Ph.D. student at the University of California, Los Angeles

Title of honors thesis: *Risky Business: The Influence of Smiling on Risky Decision-Making*

Social Ecology Excellence in Research Distinction (Spring, 2016)

Summer Undergraduate Research Opportunities Program (Summer, 2015; $1,700)

Mikaela Grimm (2015-2016)

Current position: Counseling Master's student at California State University, Fullerton

Title of honors thesis: *The Influence of Smiling on Blood Pressure*

Clint McKenna (2014-2015)

Current position: Social Psychology Ph.D. student at the University of Michigan

Title of honors thesis: *The Influence of Smiling on Evaluating Moral Foundation Transgressions*

Social Ecology Excellence in Research Distinction (Spring, 2015)

Psychology and Social Behavior Excellence in Research Award (Spring, 2015)

Summer Undergraduate Research Opportunities Program (Summer, 2014; $1,500)

Mary Smirnova (2014-2015)

Current position: Lab manager for the Trauma and Health Research on Immunity, Vitality, and Emotions Lab at the University of California, San Francisco

Title of honors thesis: *Can Smiling Make You Cheat? The Impact of Smiling on Moral Behavior*

Social Ecology Excellence in Research Distinction (Spring, 2015)

Daniel Faraci (2014-2015)

Current position: Clinical Psychology Ph.D. student at the University of South Florida

Title of honors thesis: *The Influence of Smiling on Moral Decision-Making*

Social Ecology Excellence in Research Distinction (Spring, 2015)

Summer Undergraduate Research Opportunities Program (Summer, 2014; $1,500)

CONFERENCE PRESENTATIONS

**Denotes an undergraduate student I directly supervised in research*

Invited Academic Talks

Cross, M. P. (March, 2019). *Careers in teaching psychosomatic medicine.* 77th Annual Scientific Meeting of the American Psychosomatic Society, Vancouver, Canada.

Submitted/Reviewed Academic Talks

Jenkins, B. N., **Cross, M. P.,** Goldstein, A., Kraft-Feil, T. L., Rasmussen, H., Scheier, M. F., & Pressman, S. D. (March, 2019). *The stress buffering effect of positive affect on sleep: Considering arousal level of positive affect.* Paper presentation at the 77th Annual Scientific Meeting of the American Psychosomatic Society, Vancouver, Canada.

Jenkins, B. N., Hunter, J. F., **Cross, M. P.,** Acevedo, A. M., & Pressman, S. D. (April, 2018). *Mean positive affect moderates the association between positive affect variability and immune response to the influenza vaccination.* Paper presentation at the Positive Emotion Preconference at the 5th Annual Meeting of the Society for Affective Science, Los Angeles, CA.

Pressman, S. D., Acevedo, A. M., **Cross, M. P.,** Hunter, J. F., & Jenkins, B. N. (April, 2018). *Keep calm and fight pain: How arousal matters in the positive affect-pain connection.* Paper presentation at the 5th Annual Meeting of the Society for Affective Science Annual Conference, Los Angeles, CA.

Cross, M. P., & Pressman, S. D. (March, 2018). *The case for including facial expressions in affect and health research.* Paper presentation at the 76th Annual Scientific Meeting of the American Psychosomatic Society, Louisville, KY.

Cross, M. P., Kraft, T. L., & Pressman, S. D. (April, 2016). *The impact of a "pay it forward" style kindness intervention on giver and receiver wellbeing.* Paper presentation at the 96th Annual Convention of the Western Psychological Association, Long Beach, CA.

Pressman, S. D., & **Cross, M. P.** (March, 2016). *Say cheese! The association between smiles in student identification photographs and frequency of health care center visits.* Paper presentation at the Positive Emotion Preconference at the 3rd Annual Meeting of the Society for Affective Science, Chicago, IL.

Cross, M., Brooks, K., & Robles, T. (April, 2012). *We get by with a little help from our friends: The relationship between types of social support and emotion.* Paper presentation at the Berkeley Interdisciplinary Research Conference at UCB, Berkeley, CA.

Chaired Symposia

Cross, M. P. (March, 2019). HIV. 77th Annual Scientific Meeting of the American Psychosomatic Society, Vancouver, Canada.

Cross, M. P. (March, 2018). Pain and physical symptoms. 76th Annual Scientific Meeting of the American Psychosomatic Society, Louisville, KY.

Poster Presentations

*Khan, A., Olah, M., *Palmer, S., *Smith, J., *Resendiz, E., **Cross, M. P.,** & Pressman, S. D. (April, 2019). *The relationship between personality and facial expression adherence.* Poster presentation at the 99th Annual Convention of the Western Psychological Association, Pasadena, CA.

*Kim, G. J., *Singh, T., *Hollas, K., *Tran, T., *Chen, S., *Corona, R., **Cross, M. P.,** & Pressman, S. D. (May, 2018). *An analysis of Cyberball as an effective social exclusion tool.* Poster presentation at the 30th Annual Convention of the Association for Psychological Science, San Francisco, CA.

*Dominguez Ortega, D., *Zheng, Z., *Chen, S., *Singh, T., *Galstyan, E., *Gheorma, L., **Cross, M. P.,** & Pressman, S. D. (April, 2017). *A comparison of manipulated and natural smile facial muscle activation.* Poster presentation at the 97th Annual Convention of the Western Psychological Association, Sacramento, CA.

Cross, M. P., Acevedo, A. M, Hunter, J. F., & Pressman, S. D. (March, 2017). *Smile while your heart is breaking? The protective cardiovascular effects of smiling during social exclusion.* Poster presentation at the 75th Annual Scientific Meeting of the American Psychosomatic Society, Sevilla, Spain.

Hunter, J. F., Hooker, E., Acevedo, A. M., **Cross, M. P.,** *Wong, E. & Pressman, S. D. (March, 2017). *Is your smartphone a digital security blanket? How phone use and availability influences salivary alpha amylase and exclusion reports during social stress.* Poster presentation at the 75th Annual Scientific Meeting of the American Psychosomatic Society, Sevilla, Spain.

Acevedo, A. M., Leger, K., *Shader, J., Hunter, J. F., **Cross, M. P.,** & Pressman, S. D. (March, 2017). *Keep calm and carry on: Low arousal positive affect is associated with higher parasympathetic function and no sympathetic activation during responses to pain.* Poster presentation at the 75th Annual Scientific Meeting of the American Psychosomatic Society, Sevilla, Spain.

*Dominguez Ortega, D., *Singh, T., *Zhang, S., *Koh, S. E., *Carcano, A., *Gheorma, L., **Cross, M. P.,** & Pressman, S. D. (March, 2017). *Using psychophysiological methods to understand the effects of different positive facial expression manipulations.* Poster presentation at the 38th Annual Meeting of the Society for Behavioral Medicine, San Diego, CA.

*Hofschneider, L., *Grimm, M., *Wang, H. D., *King, K., *Ochiai, K., *Ong, P., **Cross, M. P.,** & Pressman, S. D. (March, 2017). *Do loneliness and self-esteem alter the influence of self-affirmation on stress recovery?* Poster presentation at the 38th Annual Meeting of the Society for Behavioral Medicine, San Diego, CA.

Urban, E. J., Cochran, K. J., Acevedo, A., **Cross, M. P.,** Pressman, S. D., & Loftus, E. F. (January, 2017). *Underestimating pain: Memory blindness for a self-reported painful experience.* Poster presentation at the 18th Annual Meeting of the Society for Personality & Social Psychology, San Antonio, TX.

Chase, D., **Cross, M. P.,** & Pressman, S. D. (April, 2016). *Do personality traits predict health care seeking behaviors in college students?* Poster presentation at the 96th Annual Convention of the Western Psychological Association, Long Beach, CA.

*Gheorma, L., *Carcano, A., *Koh, S., *Nguy, C. T., *Ortega, D. D., *Shader, J., **Cross, M. P.,** Pressman, S. D. (April, 2016). *The smile stick: The validation of a new method of smile inducement.* Poster presentation at the 96th Annual Convention of the Western Psychological Association, Long Beach, CA.

Limas, I., Villarreal, B. J., **Cross, M. P.,** & Heckhausen, J. (April, 2016). *Academic stress, motivation, and mental and physical health in university students.* Poster presentation at the 96th Annual Convention of the Western Psychological Association, Long Beach, CA.

Cross, M. P., & Pressman, S. D. (March, 2016). *Does a smile a day keep the doctor away? The connections between facial expressions in student identification photographs and health care center visitation.* Poster presentation at the 74th Annual Scientific Meeting of the American Psychosomatic Society, Denver, CO.

Cross, M. P., *Gheorma, L., *Hofschneider, L., *Grimm, M., & Pressman, S. D. (January, 2016). *Does a smile a day keep the doctor away? The connections between facial expressions in student identification photographs and health care center visitation.* Poster presentation at the 17th Annual Meeting of the Society for Personality & Social Psychology, San Diego, CA.

*Smirnova, M., *McKenna, C., *Faraci, D. C., **Cross, M. P.,** Pressman, S. D., & Ditto, P. H. (January, 2016). *The influence of smiling on cheating.* Poster presentation at the 17th Annual Meeting of the Society for Personality & Social Psychology, San Diego, CA.

*Faraci, D. C., *McKenna, C., *Smirnova, M., **Cross, M. P.,** Pressman, S. D., & Ditto, P. H. (January, 2016). *The influence of smiling on moral decision making.* Poster presentation at the 17th Annual Meeting of the Society for Personality & Social Psychology, San Diego, CA.

*McKenna, C. *Smirnova, M., *Faraci, D. C., **Cross, M. P.,** Pressman, S. D., & Ditto, P. H. (January, 2016). *The influence of smiling on evaluating moral foundation transgressions.* Poster presentation at the 17th Annual Meeting of the Society for Personality & Social Psychology, San Diego, CA.

Cross, M. P., *Faraci, D. C., *Milligan, S., *Gheorma, L., & Pressman, S. D. (March, 2015). *Fake smiles = worse health: The connection between smile type in student photos and physical health.* Poster presentation at the 73rd Annual Scientific Meeting of the American Psychosomatic Society, Savannah, GA.

*Faraci, D. C., *Milligan, S., *Gheorma, L., **Cross, M. P.,** & Pressman, S. D. (February, 2015). *The connections between smile intensity in student ID photos and health.* Poster presentation at the 16th Annual Meeting of the Society for Personality & Social Psychology, Long Beach, CA.

Cross, M. P., Kraft, T. L., & Pressman, S. D. (February, 2015). *It's good to do good and receive good: The impact of a "pay it forward" style intervention on giver and receiver wellbeing.* Poster presentation at the 16th Annual Meeting of the Society for Personality & Social Psychology, Long Beach, CA.

Cross, M. P., Kraft, T. L., & Pressman, S. D. (February, 2015). *It's good to do good and receive good: The impact of a "pay it forward" style intervention on giver and receiver wellbeing.* Poster presentation at the Happiness and Well-being Pre-Conference, Society for Personality & Social Psychology, Long Beach, CA.

Cross, M. P., *Estevez Cores, S. M., *Bower, A. H., & Pressman, S. D. (March, 2014). *What types of social relationship variables are associated with respiratory sinus arrhythmia?* Poster presentation at the 72nd Annual Scientific Meeting of the American Psychosomatic Society in San Francisco, CA.

Leger, K. A., **Cross, M. P.,** & Pressman, S. D. (March, 2014). *The relationship between self-rated health, heart rate, and heart rate variability in healthy young adults.* Poster presentation at the 72nd Annual Scientific Meeting of the American Psychosomatic Society in San Francisco, CA.

Cross, M., Brooks, K., & Robles, T. (May, 2012). *We get by with a little help from our friends: The relationship between types of social support and emotion.* Poster presentation at the Psychology Undergraduate Research Conference at UCLA, Los Angeles, CA.

Cross, M., Frazier, M., Galligan, M., Vishnevsky, R., Thom, E., & Sandhofer, C. (2011, May). *Examining the relationship between word learning and experience within categories.* Poster presentation at the Psychology Undergraduate Research Conference at UCLA, Los Angeles, CA.

Cross, M., Frazier, M., Galligan, M., Vishnevsky, R., Thom, E., & Sandhofer, C. (May, 2011). *Examining the relationship between word learning and experience within categories.* Poster presentation at the Symposium on Cognitive and Language Development at California State University Los Angeles, Los Angeles, CA.

ADDITIONAL RELEVANT WORK EXPERIENCE

Lab Manager and Research Coordinator 2012 – 2013
Social Neuroscience Laboratory, UCLA
Principal Investigator: Shelley E. Taylor, Ph.D.

- Coordinated an NIA-funded study investigating the physiological correlates of psychological vulnerabilities to fraud across the lifespan
- Assisted in writing and editing *Health Psychology,* 9th edition, by Dr. Shelley E. Taylor
- Supported lab publications by conducting literature reviews, providing editing assistance, and coordinating submissions
- Developed and submitted research study protocols to Federal grant institutions (NIH, NSF) and UCLA's Institutional Review Board

PROFESSIONAL SERVICE

American Psychosomatic Society Emerging Leaders Committee 2017 – 2019
Responsible for promoting the development of early career members and trainees as scholars and leaders in psychosomatic medicine

American Psychosomatic Society Program Committee 2017 – 2019
Responsible for developing the academic portions of the Annual Meeting

Mentor for the International Medicine Education and Development Club at the University of California, Irvine 2018 – 2019
Serve as a mentor for two undergraduate students who are interested in careers in the health sciences

Ad Hoc Reviewer

Journal of Personality and Social Psychology

DEPARTMENTAL SERVICE

Clinical Neuropsychology and Aging Faculty Search Committee Member 2018
University of California, Irvine

Department of Psychological Science
University of California, Irvine
NSF GRFP Internal Review Committee 2018
School of Social Ecology
University of California, Irvine

Graduate Recruitment Chair 2016 – 2017
Department of Psychological Science
University of California, Irvine
Responsible for coordinating the interview weekend for potential future graduate students

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ABSTRACT OF THE DISSERTATION

The Psychological and Physiological Effects of Experimentally Induced Smiling During Physical and Social Pain

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Smiling has been shown to be beneficial in a number of social situations. One context in which smiling has not been well researched, however, is within physical health and health-relevant outcomes. The small amount of research in this area has found that smiling may buffer the cardiovascular effects of acute pain. The goals of this dissertation were to 1) investigate smiling in the context of physical and social pain and 2) examine potential mediators (orbicularis oculi activation in Study 1 and positive affect in both studies) that may underlie the connections between smiling and acute pain. In Study 1, participants were randomly assigned to make Duchenne (genuine) smiles, grimaces, or neutral facial expressions during two acute physical pain tasks. Cardiovascular responses (heart rate, respiratory sinus arrhythmia, and pre-ejection period) were measured at baseline, during the tasks, and after the tasks. Pain threshold, pain tolerance, and self-reported pain were also measured. Results showed that trajectories across cardiovascular variables of interest did not significantly differ between the facial expression conditions. There were also no significant differences in pain tolerance or self-reported pain among the conditions. However, participants who made Duchenne smiles during the cold pressor had significantly higher pain threshold levels than participants who made grimaces, although there were no differences between either of these groups and the neutral facial expression

condition. Furthermore, some evidence was found to support PA and orbicularis oculi activation as mediators of smiling and outcome variables. In Study 2, participants were randomly assigned to make Duchenne smiles or neutral facial expressions while they were included or excluded during Cyberball, a task that has been found to reliably elicit feelings of social exclusion. Results showed that participants who made Duchenne smiles while being excluded from Cyberball had significantly different heart rate trajectories than participants who were making neutral facial expressions. There were no differences in respiratory sinus arrhythmia, pre-ejection period, or self-reported pain between conditions. No evidence was found for positive affect as a mediator between smiling and outcome variables. Taken together, these studies provide some evidence that smiling during physically or socially painful situations might be beneficial.

Introduction

The connections between smiling and psychological factors have been of interest for hundreds of years. Both Charles Darwin (1872/1965) and William James (1890) posited a relationship between smiling and positive affect (PA), and researchers have continued to investigate this relationship up until the present day. Smiling plays a crucial role in human communication (e.g., Niedenthal, Mermillod, Maringer, & Hess, 2010), and it has been investigated across a variety of fields, such as whether frequency of smiles in a social interaction can predict marital conflict (e.g., Gottman, Levenson, & Woodin, 2001) and whether certain types of smiles are connected with employee burnout (e.g., Goldberg & Grandey, 2007). Most of this literature has investigated smiling as an *outcome*, for example, as an indicator of PA (e.g., Fredrickson & Levenson, 1998). However, the experimental studies within this dissertation examine smiling as a *predictor*, filling a significant gap in the positive facial expression literature. The investigation of smiling as a predictor is important because it may be the case that the simple act of smiling can lead to a variety of different psychological and physiological outcomes, which can further inform our understanding of why humans smile. This knowledge can also inform intervention designs across a variety of areas within psychology, including health psychology.

One area in which smiling has not been substantially researched is physical health and health-relevant physiological responses. A small body of literature suggests that naturally occurring smiles may be connected to important health outcomes such as lower rates of coronary heart disease ten years later (Davidson, Mostofsky, & Whang, 2010). However, research on the connections between experimentally manipulated smiles and health or health-relevant physiological outcomes is still in its infancy. Two studies have suggested that experimentally

manipulated smiling during physical pain may be beneficial for the cardiovascular recovery process (e.g., Kraft & Pressman, 2012; Pressman, Acevedo, Aucott, & Kraft-Feil, under review), but this research is limited in scope and has yet to be extensively replicated or expanded. Pain is an important domain in which to investigate smiling because smiling may alter the self-reported pain experience or dampen the physiological response to acute pain. Furthermore, smiling is relatively easy to manipulate and the creation of smiling interventions during acute pain, such as in a doctor's office during brief painful tests (e.g., needle use), would be simple and cost-effective.

The overall aim of this dissertation is to determine the effects of experimentally manipulated smiling on different types of pain. It may be that the psychological and physiological benefits of smiling during pain extend across different types of pain (e.g., physical and social pain), or may only exist for specific kinds of pain. The first study in this dissertation investigates experimentally manipulated smiling in the context of two different physical pain tasks: a cold pressor task and a pressure pain task. The second study investigates manipulated smiling in the context of a social pain task (i.e., social exclusion).

Types of Smiles

A number of different types of smiles have been suggested by a variety of researchers (e.g., Ekman & Friesen, 1982; Niedenthal et al., 2010). One of the first individuals to investigate the anatomical components of smiles was G. B. Duchenne, a French anatomist who determined that the zygomaticus major muscles in the cheeks and the orbicularis oculi muscles around the eyes were both simultaneously activated only when individuals spontaneously smiled with enjoyment (Duchenne 1862/1990). However, it took over one hundred years for empirical research to confirm Duchenne's original findings that genuine smiles of enjoyment (now called

Duchenne smiles) are distinct from other types of smiles, such as non-Duchenne ("nonenjoyment" smiles). For example, one study showed participants videos designed to induce PA and found that Duchenne smiles were both smoother and of a more consistent duration than non-Duchenne smiles (Frank, Ekman, & Friesen, 1993). Duchenne smiles also activate the left frontal lobe of the brain, an area that has been associated with certain positive emotions (e.g., Davidson, Schwartz, Saron, Bennett, & Goleman, 1979). Non-Duchenne smiles, on the other hand, do not activate this area of the brain (Fox & Davidson, 1988).

As Duchenne originally determined, Duchenne smiles are those that activate both the zygomaticus major muscles in the cheeks and the orbicularis oculi muscles around the eyes (often creating "crow's feet" on the sides of the eyes). Early studies on the Duchenne smile have connected it with reports of happiness and amusement (e.g., Ekman, Davidson, & Friesen, 1990). Most research on the Duchenne smile has supported the claim that it is a universal, genuine expression of PA. However, recent cross-cultural research has challenged this claim; one study of French-Canadian, Gabonese, and Chinese individuals found that only French-Canadian individuals used the Duchenne smile as a measure of authenticity when rating smiles within their own ethnic groups (Thibault, Levesque, Gosselin, & Hess, 2012). That said, the Duchenne smile does seem to be an indicator of genuine emotion in Western culture.

Non-Duchenne smiles, on the other hand, are those that *only* activate the muscles in the cheeks (i.e., the zygomaticus major muscles). These smiles are called a number of different terms, including "social," "fake," "insincere," "nonenjoyment," and "standard." There is some evidence that non-Duchenne smiles are not as beneficial as Duchenne smiles, and may even be harmful in some circumstances. For example, research on customer service indicates that non-Duchenne smiles can increase negative outcomes such as burnout and employee error (Goldberg

& Grandey, 2007; Wagner, Barnes, & Scott, 2014). However, other research has shown that within certain contexts, non-Duchenne smiles may have the same benefits as Duchenne smiles. The only two studies that have manipulated smiling within the context of acute pain have determined that both Duchenne smiles and non-Duchenne smiles are beneficial for cardiovascular recovery, with advantages for Duchenne smiles (Kraft & Pressman, 2012; Pressman et al., under review). These findings align with past work on facial expressions that has determined that more authentic and accurate manipulations of facial expressions are more strongly tied to the emotions that are associated with that expression (e.g., Levenson, Ekman, & Friesen, 1990).

Smiling, Health, and Physiology

There are only a handful of studies that have connected smiling with physical health or health-relevant physiology. Although physiology is not a physical health outcome in and of itself, there are a number of physiological indicators that have been connected to future health outcomes, such as blood pressure reactivity during a stressor predicting future cardiovascular outcomes (e.g., Matthews, Woodall, & Allen, 1993). Therefore, investigations of smiling and physiology are useful since most individuals smile regularly, and possible concomitant psychophysiological change may have health-relevance, thus resulting in future clinical implications. Studies conducted within this field can be divided into two separate domains: naturally occurring smiles and experimentally manipulated smiles. It is important to make this distinction because the processes that lead to naturally occurring smiles are starkly different from those that lead to experimentally manipulated smiles (i.e., a display of positive emotion vs. being instructed to manipulate specific muscles of the face). Furthermore, possible mechanisms connecting naturally occurring smiles to health and health-relevant physiology (e.g., trait PA,

better social relationships) would not translate into the context of experimentally manipulated smiles.

Naturally Occurring Smiles. One of the first studies to investigate the connections between natural smiles and physiology in the laboratory coded whether or not participants spontaneously smiled while watching a sad film clip. Participants who smiled had significantly faster cardiovascular recovery than participants who did not smile, suggesting that there may be a direct connection between smiling and physiology (Fredrickson & Levenson, 1998). Another study investigated whether facial expressions made during the first two minutes of the Type A Video Structured Interview were positively associated with ischemia (i.e., inadequate blood supply to the muscles of the heart). The Type A Structured Interview provides an assessment of certain characteristics that are associated with Type A behavior, and participants in this study were videotaped during this interview. Ischemics displayed more non-Duchenne smiles than nonischemics, but the occurrence of Duchenne smiles did not differ between the two groups (Rosenberg et al., 2001). Non-Duchenne smiles may have been more prevalent for ischemics because they felt anger more than nonischemics but were trying to manage or inhibit it. A more recent prospective longitudinal study looked at naturally occurring smiles and physical health within a large representative sample from Nova Scotia, Canada. In this study, participants went through an interpersonally stressful interview, and their levels of expressed PA were coded. Participants who expressed higher levels of PA during the interview had significantly lower rates of coronary heart disease ten years later (Davidson et al., 2010). However, one serious limitation of this study was the lack of clear operationalization of expressed PA, which included behavior (e.g., smiling), tone of responses (e.g., cheerful), and other verbal cues, thus obscuring the strength of the connection between smiling and coronary heart disease. Still, the findings from

this study suggest that there may be some connection between smiling expression and developing diseases such as coronary heart disease later in life.

Experimentally Manipulated Smiles. Early research on manipulated smiles and physiology attempted to connect different facial expressions with specific physiological outcomes. One of the earliest studies of the connections between smiling and physiology used a small sample of sixteen participants. These participants were told which facial muscles to activate and held each expression for ten seconds, during which their heart rate was continuously measured. Heart rate increased more when participants were making angry or fearful facial expressions than when they were making happy facial expressions, although heart rate increased marginally from baseline during happy facial expressions (Ekman, Levenson, & Friesen, 1983). The participants were videotaped during the tasks, and their data were only used if they were making the correct facial expressions. This study provided the first evidence of autonomic nervous system differences across facial expressions, which was later replicated, again showing larger cardiac accelerations for anger, fear, and sadness than for happiness (Levenson et al., 1990). Interestingly, another replication study questioned whether these consistent effects were due to the difficulty of the expressions rather than the expressions themselves (Boiten, 1996). In response, Levenson and Ekman (2002) reanalyzed their data from the original study and found that reported difficulty did not mediate the heart rate differences across expressions, reinforcing the idea that the specific facial expressions themselves led to these differences. Thus, manipulation of different facial expressions, including smiling, might have distinct effects on the autonomic nervous system.

As hinted at in the above literature, there are a number of factors that may affect the physiological effects of experimentally manipulated smiles. One factor that plays a role is how

well participants adhere to their facial expression conditions. Specifically, since activating the wrong facial muscles or failing to activate the correct muscles can lead to an incorrect facial expression, there may be downstream differences in psychological and physiological effects. Thus, some studies on experimentally manipulated facial expressions only include high adhering participants in analyses (e.g., Levenson et al., 1990), whereas others include adherence as a covariate in analyses (e.g., Kraft & Pressman, 2012). Another consideration is how long participants hold the manipulated facial expressions, which drastically varies across the field from only a few seconds (e.g., Ekman et al., 1983) to multiple minutes (e.g., Kraft & Pressman, 2012). The amount of time the facial expression is being held could affect any physiological changes that might be taking place; for example, physiological changes might max out after a certain length of expression, especially since naturally occurring expressions only last a few seconds (Ekman, 1984). Thus, factors such as adhering to facial expression condition and length of facial expression should be considered within studies in this area, although surprisingly, they rarely are (e.g., Wagenmakers et al., 2016).

Since the early research on experimentally manipulated smiling and physiology, researchers have recognized the importance of investigating both psychological and physiological influences of smiling within specific domains, including the context of pain.

Smiling and Physical Pain. Only two studies to date have been conducted that investigate the connections between experimentally induced smiling and pain. The first of these studies instructed participants to hold chopsticks in their mouths so that their face formed a Duchenne smile, non-Duchenne smile, or neutral facial expression. Participants were told that the study was investigating multitasking in order to reduce their reactance to smiling. Half of the participants in both of the two smiling groups were told to smile, and half were not given

instruction. Participants made their assigned facial expressions during the cold pressor task and rated their state positive and negative affect levels during baseline and immediately following the task. Regardless of whether or not participants knew they were smiling, the smiling participants had lower heart rates during recovery from the painful task, with a slight advantage for participants making Duchenne smiles (Kraft & Pressman, 2012). PA changes were in the expected direction such that participants making Duchenne smiles had marginally less of a decrease in PA than participants making neutral facial expressions, although this difference was not significant. It may be the case that smiling affects reports of PA during, but not following, painful tasks. However, this study did not include a measure of self-reported pain during the task, so it is unknown whether smiling affected pain perception in addition to a physiological process post-pain. Furthermore, the only physiological outcome included in this study was heart rate, which is controlled by both branches of the autonomic nervous system: the sympathetic nervous system (i.e., "fight or flight") and the parasympathetic nervous system (i.e., "rest and digest"). Because of this dual innervation of the heart, it is difficult to determine the exact effects of smiling on the cardiovascular system. As discussed in detail later, there is reason to believe that smiling may have specific effects on the parasympathetic nervous system, so the lower heart rates of the smiling participants in this study may have been due to an increase in parasympathetic nervous system activation. Therefore, it is important to investigate indicators of both branches of the autonomic nervous system within the context of smiling and acute pain. Nevertheless, these findings are important because they lend support to the idea that smiling may be beneficial for health by "undoing" some of the harmful effects of stressors on cardiovascular function.

The second study examined whether manipulated facial expressions during a 25-gauge needle saline injection buffered the negative psychological and physiological effects of receiving the injection (Pressman et al., under review). Participants in this study were assigned to one of four facial expression conditions: neutral facial expression, non-Duchenne smile, Duchenne smile, or grimace (a negative facial expression that activates the same muscles as a Duchenne smile along with the corrugator supercilli, the muscles in between the eyebrows, making it a more difficult expression to create). Participants held chopsticks in their mouths in different ways in order to create one of these four facial expressions. They were told that the study was investigating the effects of multitasking on needle experiences in order to prevent reactance to the facial expressions. Ratings were made for anticipation of pain, the experience of pain, and pain immediately following the injection, making this the first study to investigate self-reported pain and experimentally manipulated smiling. PA was measured at baseline and after the injection. Those making Duchenne smiles, non-Duchenne smiles, or grimaces reported significantly less anticipatory pain and less pain in response to the injection than those making neutral facial expressions. However, those who were Duchenne smiling had lower heart rates than those who were grimacing at all time points (Pressman et al., under review). PA did not mediate any of the effects; however, baseline measures of PA may have been lower than normal because participants had already read in the consent form that they were going to receive a needle injection. There were no significant differences in heart rate between Duchenne smiling and non-Duchenne smiling participants. This study demonstrates that other facial expressions such as grimacing may have beneficial effects on self-reported pain, but only smiling seems to have physiological benefits both during and immediately following the induction of acute physical pain.

Pain

The experience of pain involves two parts: pain sensation and pain affect (e.g., Rainville, 2002). Pain sensation includes information from specialized pain receptors, which provide an indication of ongoing tissue damage (e.g., Melzack & Wall, 1965). Pain affect consists of the unpleasant feelings that accompany the pain sensation (Price, 2000). Most of the original theories of pain dealt only with its physiological component (see Moayedi & Davis, 2013, for a review). However, with the introduction of the gate control theory of pain, the integral role the brain plays in the pain experience was brought to the forefront. The gate control theory posits that when a painful stimulus reaches a specific threshold, it activates pathways through the central nervous system that lead to the experience of pain (Melzack & Wall, 1965). This theory highlights psychological factors in the experience of pain as an integral part of pain processing (Melzack, 1999). The connection between smiling and pain would fit well within the framework of this theory because smiling may alter when the "gate" opens and pain is experienced.

Physical pain. There are two main types of physical pain: chronic and acute. Chronic pain is often defined as pain lasting longer than three months (e.g., from a chronic disease such as arthritis), whereas acute pain is pain lasting less than three months (e.g., from an acute injury). Stress and pain are not interchangeable concepts, but stress plays an important role in both chronic and acute pain. Chronic pain is connected to stress, and acute pain instigates a physiological stress response that contributes to the experience of pain (Chapman, Tuckett, & Song, 2008). It is nearly impossible to create chronic pain within a laboratory setting, but there are a number of techniques that have been designed to induce acute pain. For example, past research has induced acute pain through electrical nerve stimulation (Terkelsen, Molgaard, Hansen, Andersen, & Jensen, 2005) and thermal stimulation (e.g., Appelhans & Luecken, 2008).

However, one of the most common acute pain tasks in psychology is the cold pressor task, where the participant holds his or her hand in near freezing water. This task has mostly been used in past research as a stress test of cardiovascular function (e.g., Menkes et al., 1984). The physical pain associated with the cold pressor task is aching or crushing, which quickly increases in intensity until about 60 to 90 seconds (Posner, Telekes, Crowley, Phillipson, & Peck, 1985). Another example of an acute pain paradigm involves the pressure algometer, a device that is operated to increasingly apply pressure to a specific part of the body. Pressure algometers have largely been used to determine pain sensitivity in underlying tissues (e.g., Fischer, 1987). The experience of immediate pain from the cold pressor is different from the experience of the constantly increasing pain from the pressure algometer, but both tasks can provide measures of two important components of the pain experience: threshold and tolerance. Threshold occurs when the participant first begins to experience pain, and tolerance is the maximum amount of pain the participant feels that he or she can tolerate.

Simple techniques such as smiling that may lead to an increase in either threshold or tolerance may help make the pain experience and associated recovery period more bearable. Smiling may increase both threshold and tolerance because of its positive effects on the parasympathetic nervous system. A recent review of cardiovascular outcomes and pain determined that the "typical" response to pain is an increase in sympathetic nervous system activation and a decrease in parasympathetic nervous system activation, which is also seen among other stressors (Koenig, Jarczok, Ellis, Hillecke, & Thayer, 2014). Therefore, pain can be considered as a type of stress, and it has been used to induce physiological stress responses in lab settings. If smiling increases parasympathetic nervous system activation during painful tasks, this higher activation may increase the amount of time a stimulus is perceived as not painful (i.e.,

increase the amount of time until the "gate" is opened). In the case of tolerance, increased parasympathetic nervous system activation may prolong the amount of time an individual is able to tolerate a painful stimulus.

In addition to threshold and tolerance, there are a number of other outcome variables that can be measured in response to pain. Self-report measurements (i.e., asking the participant how painful a task is or how much pain they are currently in) are the most common (Breivik et al., 2008). However, self-report should not be solely relied upon because there are a number of intricacies in reporting pain. For example, self-reported pain can be affected by attitudes toward pain, which have a strong cultural component (e.g., Barak & Weisenberg, 1988; Lovering, 2006). Because of these variations in self-report, it is important to supplement with additional measures of the experience of pain, such as cardiovascular reactivity and recovery. A number of studies have investigated both cardiovascular reactivity, or the response of the cardiovascular system to stress (e.g., Matthews et al., 2004), and cardiovascular recovery, or the recovery of the cardiovascular system following stress (e.g., Hassinger, Semenchuk, & Brien, 1999), in the context of acute physical pain tasks. Cardiovascular reactivity and recovery variables are also important to measure within a separate domain of pain: social pain.

Social pain. Social pain is a specific reaction to the perception that one is being excluded from relationships or devalued by relationship partners, thus triggering painful feelings without the physical pain sensation (MacDonald & Leary, 2005). Therefore, investigating smiling in the context of social pain can determine whether smiling has specific influences on the affect component of pain instead of the physical sensation. Interestingly, physical pain and social pain share underlying neural correlates; the pattern of activation in the brain during social exclusion is similar to activation during the experience of physical pain (Eisenberger, Lieberman, &

Williams, 2003). Social pain can be manipulated in the lab in many ways, but the most common manipulations involve social exclusion. For example, one of the most popular social exclusion paradigms is Cyberball, an online ball-tossing game that reliably elicits feelings of social exclusion (Williams, Kippling, Cheung, & Choi, 2000; Williams et al., 2002). In this paradigm, the participant is told that they are playing a computer game with two participants in other rooms, but in reality, they are playing against a computer. The ball is tossed between all "participants" until about halfway through the game when the other two "participants" begin to only throw the ball to each other, excluding the true participant from the game. Although there are a number of other exclusion paradigms (e.g., the Yale Interpersonal Stressor [YIPS; Stroud, Tanofsky-Kraff, Wilfley, & Salovey, 2000]), Cyberball is the most well researched paradigm within the context of social pain.

The overlap between social and physical pain has been demonstrated in a number of different domains. One study found that participants who took a dose of Tylenol once per day reported less daily social pain than participants who took a placebo (Dewall et al., 2010). Studies have also demonstrated that physiological responses (e.g., increased heart rate; Iffland, Sansen, Catani, & Neuner, 2014) and psychological responses (e.g., feelings of being ignored or excluded; Riva, Wirth, & Williams, 2011) are similar during social and physical pain. Understanding the connections between social and physical pain is important because social pain can be detrimental and long lasting. For example, children who experience social rejection by their parents or peers are more likely to develop depression (Lefkowitz & Tesiny, 1984). Furthermore, social rejection has been found to hasten the onset of depression (Slavich, Thornton, & Monroe, 2009), and a recent meta-analysis found that social rejection decreased positive mood and self-esteem (Gerber & Wheeler, 2009). Therefore, social pain is an important

type of pain to investigate in the context of smiling because smiling may buffer the negative feelings associated with social exclusion.

Possible Mechanisms Connecting Smiling to Pain

I hypothesize two mechanisms through which smiling may influence physiology and self-reported pain: state PA and the oculocardiac reflex.

State PA. One of the mechanisms through which smiling may influence physiology and self-reported pain is state PA, or transitory PA felt in the moment. The mere act of smiling may alter or induce state PA, as posited by the facial feedback hypothesis (Tourangeau & Ellsworth, 1979). One of the first individuals to propose this concept was Charles Darwin (1872/1965), who discussed how the expression of an emotion can intensify the experience of it. A few years later, William James (1890) posited that bodily changes that accompany an emotion are, in fact, the emotion itself. In other words, emotions cannot exist if they are not expressed physiologically, including through facial expressions or some kind of physiological arousal, which is the key tenet of the James-Lange theory of emotion (James, 1890; Lange, 1885/1922).

Even though Darwin and James both set the groundwork for the facial feedback hypothesis, it did not develop into its present form until about a century later. In the 1960s and 1970s, a handful of emotion theorists began to hypothesize that facial expressions play an important role in the experience of emotion (Izard, 1971, 1977; Tomkins, 1962). Empirical evidence for this view, however, did not appear until later from a few noteworthy studies. In one of these studies, participants either frowned or smiled while viewing pictures of either Ku Klux Klan members or children playing and then self-reported on their affect (Laird, 1974). Results indicated that scores for aggression were higher for frown trials, and scores for elation, surgency, and social affection were higher for smile trials.

In possibly the most famous study of this hypothesis, participants were given a pen and assigned to one of three conditions: holding the pen with their lips (neutral facial expression), holding the pen between their teeth (smiling), or holding the pen in their nondominant hand (control; Strack, Martin, & Stepper, 1988). Importantly, a cover story was told to participants so they would not be aware of their facial expressions. Participants were shown a series of cartoons and asked to rate the funniness of each cartoon. Individuals in the smiling condition found the cartoons significantly funnier than participants in either of the other two conditions (Strack et al., 1988), providing evidence for the facial feedback hypothesis. However, a recent attempted replication of this study by 17 different labs failed (Wagenmakers et al., 2016), although there are a number of explanations as to why this may have been the case (Strack, 2016). For example, the attempted replications were conducted on university students, many of who were studying psychology and may have been familiar with the original study. Furthermore, as in the earliest experimentally manipulated smile work, there was no attention to adherence to facial expression condition nor duration of expressions. Finally, a new addition was that the researchers directed a camera onto the participants, which may have made them more self-aware than those in the original study (e.g., Hass, 1984). Indeed, a recent study replicated the original facial feedback experiment with two conditions: one with a video camera present and one without a video camera. In absence of the camera, significant facial feedback results were observed; however, when the video camera was present, these effects were eliminated (Noah, Schul, & Mayo, 2018). Although the replication attempt by Wagenmakers and colleagues (2016) is important, it does not mean that smiling should not continue to be studied in a number of different domains, including the investigation of a wider variety of outcome variables. The replication study only investigated a single outcome variable (how amused participants felt), but other outcomes may

more closely get at whether smiling affects the overall experience of PA. Furthermore, a recent meta-analysis on 138 studies of facial feedback and the emotional experience determined that the overall effect was small yet significant (d = 0.20; Coles, Larsen, & Lench, 2019). Thus, although the literature is mixed, it seems that smiling can affect PA when certain important variables are considered.

Whether smiling influences state PA is important to determine because state PA has been connected with a number of health and health-relevant outcomes. In one study, state PA measured throughout the day with ecological momentary assessment was inversely related to cortisol output (a hormone released during stress) and heart rate over the course of the day (Steptoe, Wardle, & Marmot, 2005). State PA has also been connected with survival such that individuals with higher levels of state PA over the course of one day were less likely to die than individuals with lower levels of state PA (Steptoe & Wardle, 2011). Studies such as these indicate that state PA may have important effects on various physiological systems, which may eventually result in significant differences in health outcomes such as survival. Thus, if smiling is connected with increases in state PA, smiling could affect health and health-relevant outcomes.

In addition to affecting physiology, state PA may also be connected to self-reported pain (e.g., Rhudy & Meagher, 2001). The broaden-and-build theory hypothesizes that positive emotions may broaden individuals' awareness, which can in turn build their personal resources (Fredrickson, 2001). In expanding an individual's attention, state PA may help distract from negative sensations such as pain, resulting in lower levels of self-reported pain. Because of the important role state PA may play in the connection between smiling and health-relevant outcomes, state PA will be measured multiple times throughout both studies of this dissertation.

Oculocardiac reflex. An additional untested possible mechanism through which smiling may affect physiology and self-reported pain is through activation of the oculocardiac reflex. The oculocardiac reflex is a decrease in pulse rate when pressure is applied to muscles around the eyes and/or the eyeball is compressed. One possibility is that activation of the orbicularis oculi muscles during Duchenne smiles triggers the oculocardiac reflex through a number of nerve activations, which in turn could lower pulse rate through stimulation of the vagus nerve (Lang, Lanigan, & van der Wal, 1991). The vagus nerve plays a large role in the parasympathetic nervous system, a division of the autonomic nervous system responsible for decreasing physiological arousal. Although activation of the oculocardiac reflex cannot be directly determined from the proposed studies, a comparison of orbicularis oculi activation with a measure of parasympathetic nervous system activation, such as respiratory sinus arrhythmia (RSA), is a first step toward investigating this relationship. I conduct this test in the first study of this dissertation.

Possible Covariates

Although investigating sex and cultural differences is not a primary goal of this dissertation, it is important to note that these differences exist within the context of both the smiling and experimental pain literatures. These factors may alter how smiling works and how pain is reported. Information on the sex and ethnicity of participants will be collected in both studies of this dissertation so these variables can be controlled for in analyses. Additional variables that matter within the experimental pain and/or smiling experience (e.g., attitudes toward pain, pain catastrophizing, trait affect) will be touched upon in the context of each study.

Sex. There is a robust literature that suggests there are differences in smiling between men and women. For example, a meta-analysis of 162 studies determined that women are more

likely to smile than men (d = 0.41; LaFrance, Hecht, & Paluck, 2003). The fact that women naturally smile more than men may mean that they feel more comfortable manipulating their face into a smile in an experimental setting, and, therefore, are more adherent to the smiling condition. There is also a large literature suggesting that there are significant differences in the experience of experimental pain between men and women. A meta-analysis determined that females display greater pain sensitivity to experimental pain than males, and the effect size for this relationship was moderate to large (Riley III, Robinson, Wise, Myers, & Fillingim, 1998). Interestingly, this difference may be especially large in pressure pain tasks that involve threshold and tolerance measures. Therefore, it is important to control for sex within analyses to minimize these pre-existing differences.

Culture. There are also important differences in how emotions are expressed via the face across cultures. Although many early studies supported the universality of facial expressions (e.g., Ekman et al., 1987; Izard, 1971), current researchers have begun to take more intermediary stances by arguing that there are some universalities and some culture specifics of facial expressions of emotion (e.g., Elfenbein & Ambady, 2003). Even though smiling may be a universal indicator of happiness, there are still important cultural differences. For example, one study presented preschool children with pictures of faces with either a big ("excited") smile or a smaller ("calm") smile and asked them which face they would rather be. European American preschool children were 3.5 times more likely to prefer an excited smile over a calm smile than Taiwanese Chinese preschool children (Tsai, Louie, Chen, & Uchida, 2007). Thus, different display norms across cultures may affect how activated certain facial muscles are during experimentally manipulated smiling.

Culture also plays a role in the context of pain. A number of studies have investigated experimental pain within specific ethnicities and have found important differences across a variety of pain tasks. For example, one study found that African American participants had lower tolerance for both heat and cold pain than European American participants, although thresholds and ratings of intensity did not differ between groups (Campbell, Edwards, & Fillingim, 2005). Studies such as this suggest that cultural differences in the experience of pain may be more pronounced for the affective component of pain versus the sensory component (Green et al., 2003). Since many of my measures of interest focus on the affective component of pain, culture is also important to consider in analyses.

Aims of the Dissertation

The overall aim of this dissertation was to fill important gaps in the literature on experimentally manipulated smiling and pain. To date, the only acute pain tasks that have been investigated in this context are a saline needle injection (Pressman et al., under review) and the cold pressor task (Kraft & Pressman, 2012). It is important to investigate experimentally manipulated smiling within different pain tasks in order to determine psychological and physiological benefits that smiling may confer, and when/where in the pain experience these benefits occur. Furthermore, the scope of outcome variables that have been investigated in the experimentally manipulated smiling and pain literature is limited. These studies add a wider variety of cardiovascular measures, including indicators of sympathetic and parasympathetic nervous system activation, and self-report measures such as threshold and tolerance. With the addition of these outcome variables, these studies determine what specific aspects of the multidimensional pain experience experimentally manipulated smiling affects.

The specific aim of Studies 1 and 2 was to determine the effect of experimentally induced smiling on the negative psychological and physiological effects of three distinct types of pain-inducing tasks: a pressure pain task, the cold pressor task, (both in Study 1), and a social pain task (Study 2). Study 1 included both a pressure pain task and the cold pressor task to determine whether smiling influences either threshold or tolerance during these tasks. By including both of these tasks in the same study, I determined whether experimentally manipulated smiling differently affected the two types of physical pain (sudden and crushing in the cold pressor task, slowly increasing pressure in the pressure pain task). This comparison is important in determining the generalizability of smiling during physical pain and what aspects of pain are affected by an experimental smiling manipulation.

Another important component of Study 1 was the ability to test a possible mechanism underlying the relationship between smiling during physical pain and faster cardiovascular recovery. The activation of the orbicularis oculi muscles around the eyes may initiate the oculocardiac reflex, which in turn lowers pulse via the vagus nerve. By measuring RSA (an indicator of parasympathetic nervous system activation) during the course of the study, I investigated whether higher levels of orbicularis oculi activation during the physical pain tasks mediate the relationship between smiling and parasympathetic nervous system activation. This untested mechanism is important because it could demonstrate a specific component of smiling that is directly connected to the cardiovascular system. In order to test my other proposed mechanism, PA, I measured PA both during *and* following each physically painful task. Experimentally manipulated smiling may have only brief effects on PA that may not carry over to the recovery period, so it is important to attain a measure of PA *during* the painful tasks. This

has not been investigated in past literature and will help determine when and if experimentally manipulated smiling influences PA.

Study 2 investigated smiling within the context of social pain. Because social pain and physical pain share neural correlates (Eisenberger et al., 2003), it was reasonable to expect that smiling may confer cardiovascular benefits during social exclusion. Experimentally manipulated smiling has never been tested in the context of social pain before, but this is an important investigation because it can provide support for the overlap between physical and social pain. If smiling confers the same psychological and physiological benefits during both physical and social pain, this provides evidence for the overlap between these two phenomena. Furthermore, this investigation provides a new level of depth toward the understanding of how exactly smiling can affect both physical and social pain.

Study 1

Overview

The goal of Study 1 was to determine whether experimentally manipulated smiling buffered the negative psychological and physiological effects of a pressure pain task and a cold pressor task. Heart rate (HR), heart rate variability (HRV), and impedance cardiography (ICG) were collected during the study in order to investigate cardiovascular reactivity and recovery. HR is controlled by both branches of the autonomic nervous system, the sympathetic nervous system and the parasympathetic nervous system. HRV is a measure of the flexibility and adaptability of the cardiovascular system (Thayer, Åhs, Fredrikson, Sollers, & Wager, 2012), whereas ICG is a measure of cardiovascular time measures and cardiac output (Sherwood et al., 1990). Specific indices can be derived from HRV and ICG to determine the level of activation of the sympathetic and parasympathetic nervous systems. Pre-ejection period (PEP), a measure of cardiac

contractility (a healthy ventricle has a short PEP), was used as an indicator of sympathetic nervous system activity. RSA, a rhythm in the beat-to-beat heart pattern that is naturally occurring (Denver, Reed, & Porges, 2007), was used as an indicator of parasympathetic nervous system activity. Cardiovascular reactivity (i.e., the response of the cardiovascular system to stress) and recovery (i.e., the extent to which elevations in the cardiovascular system persist after stress) are both important to investigate within the context of smiling and pain. Smiling may affect the initial response of the sympathetic and parasympathetic nervous systems, but may also affect the recovery process within these two systems following the experience of pain.

In addition to Duchenne smiles and neutral facial expressions, I also included grimaces in this study for two reasons. First, Duchenne smiles are difficult expressions to make and could serve as distractions during pain. Grimaces activate the same muscles as Duchenne smiles *plus* the corrugator supercilli (muscles in between the eyebrows). Thus, if results are found for Duchenne smiles but not grimaces, I can rule out the distraction of making a difficult facial expression during pain as an alternative explanation for the findings. Second, the inclusion of grimaces allows me to unpack the role of PA in my findings, since I would expect PA to only be associated with Duchenne smiles and not grimaces.

Hypotheses

I hypothesized that participants who were randomly assigned to make Duchenne smiles during both the pressure pain and cold pressor tasks would have different cardiovascular trajectories (across HR, RSA, and PEP) than participants who were randomly assigned to make grimaces or neutral facial expressions, driven by lower cardiovascular reactivity during the tasks and faster cardiovascular recovery after the tasks. I further hypothesized that participants who were randomly assigned to make Duchenne smiles during both tasks would have higher pain

threshold and tolerance levels than participants who were randomly assigned to make grimaces or neutral facial expressions. Furthermore, I hypothesized that participants who were randomly assigned to make Duchenne smiles or grimaces would self-report lower levels of pain during the tasks than participants who were randomly assigned to make neutral facial expressions. I also hypothesized that PA would mediate the relationship between smiling and the four main outcome variables of interest (HR, RSA, PEP, and self-reported pain). Finally, I hypothesized that orbicularis oculi activity would mediate the relationship between smiling and RSA.

Pre-Registration

I pre-registered the method and planned analyses on the Open Science Framework. This was done on September 14, 2018, prior to data analysis.

Method

Participants. Participants were 233 undergraduate students at the University of California, Irvine, who completed the study for either course credit or pay (based on a power analysis with power set at 0.9 and effect size set at 0.25 [medium effect size]). Participants were excluded from the study if they had a psychological disorder (e.g., clinical depression, anxiety disorder, bipolar disorder) for which they were currently being treated (e.g., medication, therapy); had a facial muscular disorder; were not fluent in English (both reading and writing); ingested caffeine in the two hours prior to the study (affects cardiovascular functioning); had a condition or disorder causing them to faint frequently; had cardiovascular or neurocardiogenic syncope; had a cardiovascular condition (e.g., a heart condition, hypertension); had a chronic pain condition; took medication not approved by the study team that day (e.g., mood-altering or pain-altering medication); had sensitive skin or any adverse skin reaction from band aids or cosmetic facial products; or consumed alcohol the day of the study. One participant was

excluded from analyses because they took medication not approved by the study team the day of the study. The final sample size was 232 participants (68.5% female, mean age = 20.39). Participants who completed the study for pay were compensated $5 for every 30 minutes completed of the study. The ethnicity breakdown of the participants was 52.6% Asian or Pacific Islander, 22.8% Hispanic or Latino, 9.5% White or Caucasian, 6.0% biracial, 4.3% Black or African-American, and 4.7% other.

Procedure. Upon arrival to the lab, participants were consented and told that the purpose of the study was to investigate multi-tasking in the context of stress. Participants completed a screening questionnaire, and if they were not eligible for the study, they were thanked for their time and dismissed. If participants were eligible, they were randomly assigned to one of three facial expression conditions: neutral facial expression, grimace, or Duchenne smile.

Participants' weight, height, waist, hip, and arm circumference were measured by the researchers. Participants were asked to remove all jewelry and pin their hair up out of their face, and then the researchers connected them to the electrocardiogram (ECG) and electromyogram (EMG). Four electrodes were placed on the participant's core and two electrodes were placed on their back in order to measure HRV and ICG. Electrode areas were cleaned with alcohol wipes before electrodes were applied to the skin. Facial EMG sensors were applied to the left side of the participants' faces as past research has shown that the left side of the face is more expressive (Mandal, Asthana, & Pandey, 1995). One electrode was placed on the forehead to serve as a ground. Two electrodes were placed diagonally on the left cheek on the zygomaticus major muscle, and two electrodes were placed below the left eye on the orbicularis oculi muscle. Before electrodes were applied, each area was cleaned with an alcohol wipe and abraded with an exfoliating scrub. Participants were video recorded throughout the study in order to code for

adherence to facial expression condition. The researchers then left the room while the participant completed baseline questionnaires. Upon completion of these questionnaires, the participant sat quietly for five minutes in order to attain baseline physiological data.

After the baseline physiological data collection period, research assistants trained participants on their assigned facial expressions. This period began with the opening statement, "At this time, we are going to train you on the multitasking portion of the study, which includes training you on how to hold the chopsticks in your mouth in a specific position." For each facial expression condition, participants were shown a picture of the same woman holding the chopsticks in her mouth in the appropriate way; this picture remained near the participant as a reference for the remainder of the study. For the Duchenne smile condition, participants were instructed to, "Please hold the chopsticks sideways in your mouth tightly. Push them back as far as they can comfortably go, just like the woman in the picture. Make sure your teeth are showing at all times" (refer to Figure 1). For the grimace condition, participants were instructed to, "Please hold the chopsticks sideways in your mouth tightly just like the woman in the picture. Ensure that you are holding the chopsticks tightly, pushing them as far back in your mouth as possible, while also squinting your eyes and wrinkling your forehead. To get the forehead position correct, it might help to imagine that you have to hold something like a penny between your eyebrows" (refer to Figure 2). For the neutral facial expression condition, participants were instructed to, "Please hold the chopsticks gently with your front teeth just like the woman in the picture" (refer to Figure 3). Participants were asked to mimic the person in the photograph as closely as possible and were given feedback on their facial expression manipulations during this training period. Participants held the facial expression during the training session for no longer than ten seconds.

Next, participants engaged in two separate tasks during which continuous HRV, ICG, and EMG were taken (pain tasks were counterbalanced). Before the beginning of the first task, participants were told that they would be asked questions during each task and were presented with a few practice questions on a tablet so they could become familiar with the response format. Participants placed the chopsticks in their mouths in order to create their assigned facial expressions immediately before the start of each task. They held the facial expressions throughout the duration of each task and removed the chopsticks from their mouths as soon as the task ended. Following each task, the participants rested quietly for five minutes (recovery period) before continuing with the experiment (facial expressions were not held during this period).

One task involved up to four minutes of applying pressure of 5 kilopascals (kPa) per second with the pressure algometer with a 1 cm diameter probe on the muscle belly of the first dorsal interosseous muscle (the muscle between the thumb and the index finger; Figure 4) of the participant's' dominant hand until the participant signaled that the pressure had become too uncomfortable to bear (tolerance). The pressure test ended if the participant's pressure tolerance reached 1500 kPa (no more than four minutes). Participants were asked to indicate when they first felt pain during the task (threshold) and this time was recorded. Pain was measured up to nine time points during the task (every 30 seconds, including the very beginning and end of the task) using a scale of 0 (no pain) to 100 (most pain imaginable).

Figure 1. The picture participants in the Duchenne smile condition were asked to mimic.

Figure 2. The picture participants in the grimace condition were asked to mimic.

Figure 3. The picture participants in the neutral facial expression condition were asked to mimic.

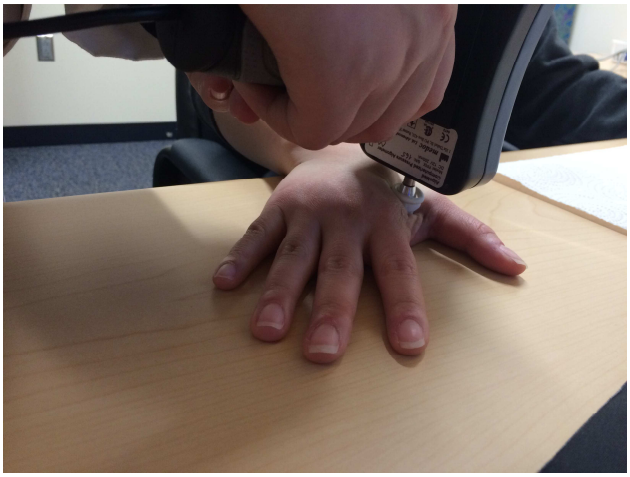

Figure 4. The placing of the pressure algometer on the muscle belly of the first dorsal interosseous muscle.

During the other task, participants immersed their nondominant hand into cold water, leaving the dominant hand free for pain ratings. The apparatus had continuously circulating

water at a temperature of 4° Celsius (39.2° Fahrenheit). A water pump and thermometer were used to ensure a precise and constant temperature. Participants were told that they could remove their hand from the water if they felt too much pain (tolerance). The researcher had a stopwatch to measure immersion time. The cold pressor task lasted a maximum of four minutes. Participants were asked to indicate when they first felt pain during the task (threshold) and this time was recorded. Pain was measured on a tablet up to nine time points during the task (every 30 seconds, including the very beginning and end of the task) using a scale of 0 (no pain) to 100 (most pain imaginable). After the recovery period, they were given two brief questionnaires regarding their current mood and current pain, followed by several additional short questions probing their coping with the pain. Upon completion of the final questionnaires, participants were unhooked from the physiological equipment and debriefed about the true purpose of the study.

Measures.

Physiological.

Cardiovascular measures. A three-lead ECG and a four-lead ICG were registered using 1.5 inch disposable silver electrodes (Mindware Technologies, Ltd.). HRV and ICG analysis software Mindware Version 3.1.2 was used to clean the data. R peaks were marked unless artifacts made it impossible to identify them, in which case that part of the segment was removed. If the remaining data in that 60-second segment was not at least 30 seconds of continuous data, then it was omitted from analyses. Furthermore, an averaged ensemble of the ECG and ICG waveforms from each 60-second segment was created, each of which was visually inspected for accuracy in labeling event points in the cardiovascular cycle. Three main cardiac autonomic measures of interest were derived from the ECG and ICG data: HR, RSA, and PEP.

Facial muscle activation measures. A four-lead EMG was registered using 4 mm reusable silver chloride electrodes (Mindware Technologies, Ltd.). Zygomaticus major and orbicularis oculi muscle activity were both measured continuously during baseline, reactivity during both pain tasks, and recovery following both pain tasks. The sensors were set to record at a sample rate of 500 Hz, gain at 2000 Hz, low cutoff at 20 Hz, and high cutoff at 200 Hz. EMG analysis software Mindware Version 3.1.2 was used to clean EMG data prior to analysis by removing the portions in which the participants made movements that interfered with facial muscles of interest, such as yawning or sneezing.

Self-reported pain. During the pressure algometer task and the cold pressor task, participants were asked the following question every 30 seconds to measure pain: "On a scale of 0-100 where 0 is no pain and 100 is the worst possible pain, please rate your current level of pain." Participants were also asked to indicate when they first experienced pain (threshold) during both tasks; threshold time was recorded for both tasks, and threshold pressure was recorded for the pressure algometer task. When the participants stopped each task, tolerance time was recorded (tolerance pressure was also recorded for the pressure algometer task).

Self-reported affect. During the pressure algometer task and the cold pressor task, participants were asked the following questions every 30 seconds: "How positive (e.g., excited, happy, calm) do you feel right now?" and "How negative (e.g., angry, anxious, sad) do you feel right now?" Both of these were asked on a 0 (not at all) to 100 (extremely) scale.

A variation of the Profile of Mood States (POMS; McNair et al., 1971; Usala & Hertzog, 1989) was used to measure trait and state affect (21 items). PA items were active, calm, cheerful, energized, enthusiastic, happy, lively, quiet, and relaxed. Negative affect (NA) items were anxious, bored, drowsy, intense, jittery, nervous, overwhelmed, passive, sad, stressed, tired, and

unhappy. To measure trait affect, participants were asked, “When considering how you usually are and how you feel on average, to what extent have you felt each of the following emotions?” Participants rated their trait affect on a 1 (very slightly/not at all) to 5 (very much) scale. To measure state affect, participants were asked, “Consider how you are feeling and evaluate the following items based on how accurately that feeling describes you AT THIS MOMENT.” Participants rated their state affect on a 1 (not at all accurate) to 5 (extremely accurate) scale. State affect was measured two times throughout the study: once after the pressure pain task and once after the cold pressor task.

Covariates. Age, sex, and ethnicity were collected. Participants were asked about a number of health behaviors known to influence cardiovascular functioning, including smoking, drinking, exercising, and sleeping. Levels of perceived stress were measured by the Perceived Stress Scale (4-item; Cohen, Kamarck, & Mermelstein, 1983). Levels of depression were measured by the Center for Epidemiological Studies Depression Scale (10-item; Radloff, 1977). Attitudes toward pain were measured with the Pain Attitudes Questionnaire, Revised (Yong, Bell, Workman, & Gibson, 2003), a 24-item survey that measures pain-related stoicism and cautiousness. Four subscales were calculated for this scale: Stoic-Reticence, Stoic-Superiority, Cautious-Self-Doubt, and Cautious-Reticence. Pain catastrophizing was measured with the 13-item Pain Catastrophizing Scale (Sullivan, Bishop, & Pivik, 1995).

Facial coding. Three coders trained in facial muscle activation independently coded the videos of participants holding the chopsticks in their mouths during the cold pressor and pressure algometer task. Each coder gave each participant an overall adherence score, ranging from 1 (held the facial expression 10% of the time) to 10 (held the facial expression for 100% of the time). Cohen’s kappa values ranged from .55 to .64 across the two tasks, which have been

suggested in recent literature to represent weak to moderate agreement among coders (McHugh, 2012). Average adherence was 1.43 during the pressure algometer task and 1.66 during the cold pressor for the Duchenne smile condition; 2.30 during the pressure algometer task and 2.42 during the cold pressor for the grimace condition; and 9.75 during the pressure algometer task and 9.43 during the cold pressor for the neutral facial expression condition. Overall adherence scores were averaged across coders to create an overall adherence variable.

Data analysis.

Main analyses. The main cardiovascular physiological response variables of interest were HR, RSA, and PEP. For cardiovascular reactivity and recovery analyses (looking at HR, RSA, and PEP separately), multi-level modeling was used to examine whether the trajectories differed across the three facial expression conditions. There were ten time intervals; average baseline, four one-minute intervals during either the pressure pain task or cold pressor task (reactivity), and five one-minute intervals post task (recovery). The amount of variation that existed at each level was assessed using an unconditional means model with no predictors entered. An unconditional growth model was examined to determine whether within-person variation was systematically associated with time (maximum likelihood estimations indicated that quadratic time was the most appropriate to include for all cardiovascular outcome variables). A random intercept, random slope, and random quadratic slope improved all model fits so were included on the random effects side of the models. The Duchenne smile condition was chosen as the reference group for the main models because it was the condition of highest interest to study hypotheses. Pairwise contrasts were used to compare both the trajectories of the cardiovascular variables of interest between all conditions and levels of cardiovascular variables of interest at each time point between all conditions.

The main self-reported outcome variables of interest were pain threshold, pain tolerance, and self-reported pain. Linear regressions were conducted to compare pain threshold and tolerance levels between the three facial expression conditions, which were dummy coded. A change score for self-reported pain was calculated by averaging pain reported every 30 seconds during each of the tasks and subtracting self-reported pain from immediately before the tasks from these averages. Linear regressions were conducted to compare self-reported pain levels between the three facial expression conditions, which were dummy coded.

Covariates that were considered in analyses were age, sex, ethnicity, body mass index (BMI), smoking status, drinking, exercise, sleep, trait affect, perceived stress, depression, attitudes toward pain, and pain catastrophizing. If any of these covariates were associated with the dependent variable of interest, they were controlled for within the analysis.

Tools for determining sample size for studies using multilevel modeling with continuous predictors that are adequately powered are not well established. However, simulation studies suggest that when *N* is at least 50 at Level 2, estimates (both coefficient and variance) are minimally biased (e.g., Maas & Hox, 2005). The sample sizes in both studies in this dissertation were more than four times the recommended size ($N = 233$ for Study 1 and $N = 334$ for Study 2).

Mediation analyses. Seemingly unrelated regressions were used throughout this dissertation to conduct mediation analyses. This method has been demonstrated to more efficiently estimate regression coefficients than running single-equation least-squares models (Zellner, 1962). The two proposed mediators were PA and orbicularis oculi activation. Seemingly unrelated regressions were used to determine whether PA mediated the relationship between smiling and the three main cardiovascular variables of interest (HR, RSA, and PEP) during reactivity and recovery. Change scores for PA were calculated by averaging how positive

the participants felt every 30 seconds during each of the tasks and subtracting baseline PA from immediately before the tasks from these averages, which was tested as the mediator in regression analyses. Reactivity and recovery change scores for cardiovascular variables of interest were calculated by subtracting average baseline levels from average reactivity and recovery levels. Seemingly unrelated regressions were also used to determine whether PA mediated the relationship between smiling and self-reported pain.

Furthermore, seemingly unrelated regressions were used to determine whether orbicularis oculi activation mediated the relationship between smiling and RSA. The independent variable was whether participants were making Duchenne smiles or neutral facial expressions; thus, mediation analyses were only conducted between the Duchenne smile and neutral facial expression conditions. Change scores for orbicularis oculi activation were calculated by averaging mean muscle activation during each of the tasks and subtracting mean baseline muscle activation from these averages, which was tested as the mediator in regression analyses. As in PA mediation analyses, reactivity and recovery change scores for RSA were calculated by subtracting average baseline levels from average reactivity and recovery levels.

Outliers. Participants were considered outliers and excluded from analyses if they were three or more standard deviations above or below the mean of the dependent variable.

Results

HR. The means, standard deviations, and ranges of HR during baseline, reactivity (for both pain tasks), and recovery (for both pain tasks) are reported in Table 1.

Table 1. Descriptive statistics for HR during baseline, reactivity, and recovery for each pain task and each condition.

	Time														
	Baseline			Reactivity (pressure algometer)			Recovery (pressure algometer)			Reactivity (cold pressor)			Recovery (cold pressor)		
Condition	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*
Duchenne smile	75.47	9.94	51.79-100.51	77.94	9.83	53.67-107.06	74.56	9.23	52.40-96.42	83.11	10.69	60.85-113.19	74.39	9.65	51.90-97.68
Grimace	72.78	9.57	53.64-101.46	75.13	10.46	53.48-100.55	71.58	9.50	54.46-96.38	81.72	11.11	60.41-106.11	71.43	9.64	52.73-95.33
Neutral facial expression	74.15	9.80	52.33-100.97	76.77	9.87	56.02-98.55	73.50	9.58	52.73-99.16	83.43	11.57	58.03-117.02	72.86	9.38	53.73-97.25

Pressure algometer task. Nine participants were outliers and were dropped from analyses. An unconditional means model showed that 83.20% of the variation in HR was due to between-person differences and 16.80% of the variation in HR was due to within-person differences. An unconditional linear growth model showed that there was significant between-person variation in change over time. No covariates significantly improved the model fit, so none were included in the final model. The final model predicting HR responses to the pressure algometer task included the interaction between the quadratic form of time and facial expression condition. The interaction between condition and quadratic time was not significant ($\chi^2 = 0.93$, $p = .63$); therefore, the quadratic rate of change in HR was not different across conditions (Table 2).

Table 2. Multilevel between-person effects of the interaction between facial expression condition, time, and quadratic time on rate of change in HR during the pressure algometer task.

Variable	Coefficients (RSE)	95% CI
Fixed Effects		
Intercept	76.06(1.19)***	[73.73, 78.40]
Time	0.30(0.24)	[-0.18, 0.77]
Condition		
Grimace	-2.04(1.64)	[-5.25, 1.16]
Neutral	-0.72(1.68)	[-4.02, 2.58]
Condition^{x}time		
Grimace	-0.27(0.33)	[-0.92, 0.38]
Neutral	0.10(0.35)	[-0.58, 0.78]
Condition^{x}time^{x}time		
Grimace	0.03(0.04)	[-0.05, 0.10]
Neutral	-0.01(0.04)	[-0.09, 0.07]
Random Effects	Estimate (RSE)	95% CI
Random Part		
Random Intercept ($\hat{\sigma}_o^2$)	89.04(9.18)	[72.75, 108.99]
Random Slope ($\hat{\sigma}_1^2$)	$3.52^{x}10^{-17}$ ($1.07^{x}10^{-16}$)	[$6.05^{x}10^{-21}$, $1.05^{x}10^{-13}$]
Random Quadratic Slope ($\hat{\sigma}_2^2$)	0.004(.0006)	[.003, .005]
Residual Variance	18.28(1.54)	[15.50, 21.57]

Note: Based on 223 participants with 1,966 longitudinal records. Duchenne smile was the reference group for facial expression condition.
RSE = robust standard error
***$p \leq .001$

Contrary to hypotheses, HR trajectories were not significantly different between the Duchenne smile and grimace conditions (γ = 0.03, z = 0.65, p = .51; Figure 5) or the Duchenne smile and neutral facial expression conditions (γ = -0.01, z = -0.26, p = .79). Furthermore, HR trajectories were not significantly different between the grimace condition and the neutral facial expression condition (γ = -0.04, z = -0.93, p = .35). Multiple comparisons confirmed that HR was not significantly different between any of the conditions at any of the ten time points.

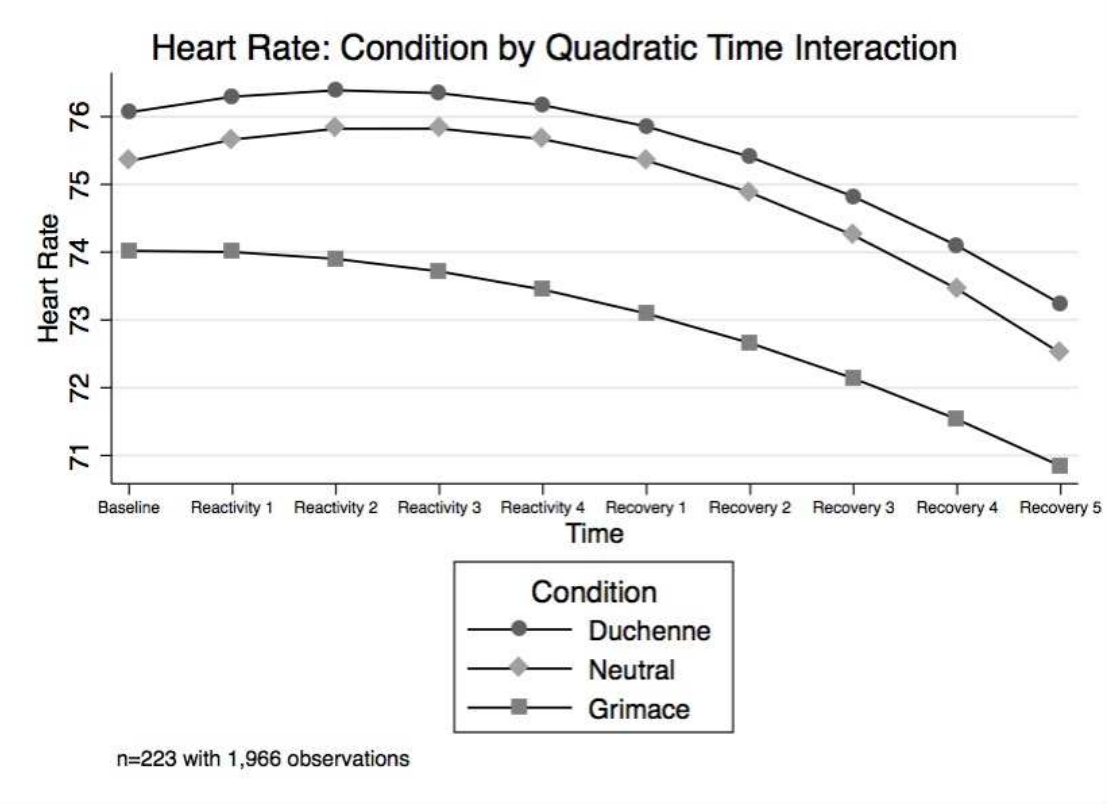

Figure 5. HR response to the pressure algometer task by condition over time.

Cold pressor. Seven participants were outliers and were dropped from analyses. An unconditional means model showed that 76.85% of the variation in HR was due to between-person differences and 23.15% of the variation in HR was due to within-person differences. An unconditional linear growth model showed that there was significant between-person variation in change over time. The final model predicting HR responses to the cold pressor included BMI, exercise, and the Cautious-Reticence subscale of the Pain Attitudes Questionnaire, Revised (Yong et al., 2003), as covariates and the interaction between the quadratic form of time and facial expression condition. The interaction between condition and quadratic time was not significant ($\chi^2 = 2.66$, $p = .26$); therefore, the quadratic rate of change in HR was not different across conditions (Table 3).

Table 3. Multilevel between-person effects of the interaction between facial expression condition, time, and quadratic time on rate of change in HR during the cold pressor.

Variable	Coefficients (RSE)	95% CI
Fixed Effects		
Intercept	74.09(3.89)***	[66.47, 81.71]
BMI	0.35(0.13)**	[0.10, 0.60]
Exercise	4.34(1.93)*	[0.56, 8.11]
Cautious-Reticence	-0.24(0.19)	[-0.62, 0.14]
Time	0.41(0.29)	[-0.15, 0.97]
Condition		
Grimace	-1.79(1.71)	[-5.13, 1.56]
Neutral	-0.54(1.69)	[-3.85, 2.78]
Condition^{x}time		
Grimace	-0.35(0.40)	[-1.12, 0.43]
Neutral	-0.71(0.40)	[-1.49, 0.07]
Condition^{x}time^{x}time		
Grimace	0.04(0.05)	[-0.06, 0.13]
Neutral	0.08(0.05)	[-0.02, 0.17]
Random Effects	Estimate (RSE)	95% CI
Random Part		
Random Intercept ($\hat{\sigma}_o^2$)	88.89(9.58)	[71.96, 109.79]
Random Slope ($\hat{\sigma}_1^2$)	$2.43^{x}10^{-10}$ ($1.09^{x}10^{-8}$)	[$1.73^{x}10^{-48}$, $3.40^{x}10^{28}$]
Random Quadratic Slope ($\hat{\sigma}_2^2$)	0.002(.0006)	[.002, .004]
Residual Variance	29.23(2.02)	[25.53, 33.46]

Note: Based on 225 participants with 1,779 longitudinal records. Duchenne smile was the reference group for facial expression condition.
RSE = robust standard error
*$p \leq .05$
**$p \leq .01$
***$p \leq .001$

Contrary to hypotheses, HR trajectories were not significantly different between the Duchenne smile and grimace conditions ($\gamma = 0.04$, $z = 0.75$, $p = .45$; Figure 6) or the Duchenne smile and neutral facial expression conditions ($\gamma = 0.08$, $z = 1.63$, $p = .10$). Furthermore, HR trajectories were not significantly different between the grimace condition and the neutral facial

expression condition (γ = 0.04, z = 0.91, p = .36). Multiple comparisons confirmed that HR was not significantly different between any of the conditions at any of the ten time points.

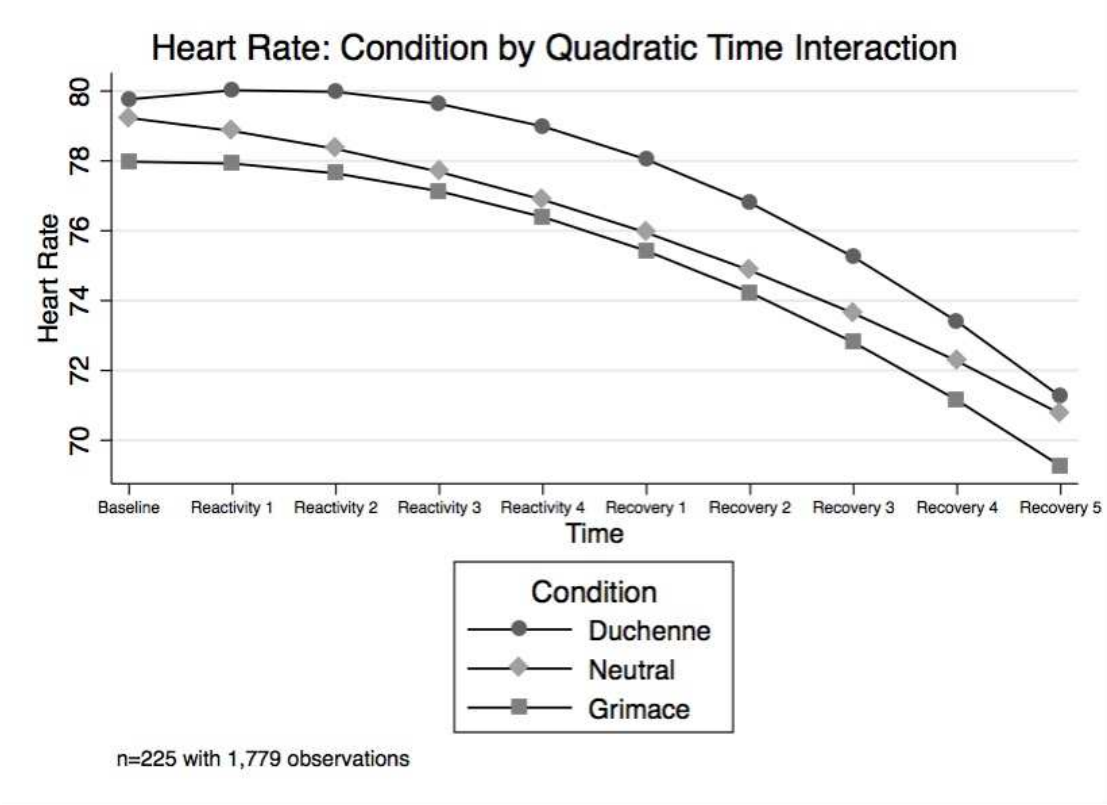

Figure 6. HR response to the cold pressor by condition over time.

RSA. The means, standard deviations, and ranges of RSA during baseline, reactivity (for both pain tasks), and recovery (for both pain tasks) are reported in Table 4.

Table 4. Descriptive statistics for RSA during baseline, reactivity, and recovery for each pain task and each condition.

	Time														
	Baseline			Reactivity (pressure algometer)			Recovery (pressure algometer)			Reactivity (cold pressor)			Recovery (cold pressor)		
Condition	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*
Duchenne smile	6.49	1.03	3.57-8.55	6.25	0.90	4.21-8.43	6.52	0.99	3.98-8.56	6.00	1.02	3.83-8.87	6.64	0.93	3.75-8.59
Grimace	6.68	1.00	3.67-9.04	6.33	0.90	3.81-8.29	6.69	0.92	3.98-8.92	6.11	1.04	3.93-8.37	6.79	1.00	4.17-9.17
Neutral facial expression	6.53	0.83	4.83-8.96	6.25	0.91	3.72-8.03	6.55	0.83	4.29-8.57	5.95	0.97	3.43-7.87	6.61	0.80	4.82-8.76

Pressure algometer task. Eight participants were outliers and were dropped from analyses. An unconditional means model showed that 61.17% of the variation in RSA was due to between-person differences and 28.83% of the variation in RSA was due to within-person differences. An unconditional linear growth model showed that there was significant between-person variation in change over time. The final model predicting RSA responses to the pressure algometer task included exercise as a covariate and the interaction between the quadratic form of time and facial expression condition. The interaction between condition and quadratic time was not significant ($\chi^2 = 0.57$, $p = .75$); therefore, the quadratic rate of change in RSA was not different across conditions (Table 5).

Table 5. Multilevel between-person effects of the interaction between facial expression condition, time, and quadratic time on rate of change in RSA during the pressure algometer task.

Variable	Coefficients (RSE)	95% CI
Fixed Effects		
Intercept	6.42(0.10)***	[6.22, 6.61]
Exercise	-0.31(0.13)*	[-0.57, -0.06]
Time	0.03(0.13)	[-0.24, 0.09]
Condition		
Grimace	0.08(0.14)	[-0.19, 0.35]
Neutral	0.01(0.14)	[-0.23, 0.31]
Condition^{x}time		
Grimace	0.04(0.05)	[-0.05, 0.13]
Neutral	0.01(0.05)	[-0.08, 0.10]
Condition^{x}time^{x}time		
Grimace	-0.004(0.01)	[-0.01, 0.007]
Neutral	-0.0006(0.006)	[-0.01, 0.01]
Random Effects	Estimate (RSE)	95% CI
Random Part		
Random Intercept ($\hat{\sigma}_o^2$)	0.57(0.06)	[0.46, 0.69]
Random Slope ($\hat{\sigma}_1^2$)	$4.15^{x}10^{-21}$ ($1.80^{x}10^{-19}$)	[$5.57^{x}10^{-58}$, $3.09^{x}10^{16}$]
Random Quadratic Slope ($\hat{\sigma}_2^2$)	$3.06^{x}10^{-5}$ ($7.28^{x}10^{-6}$)	[$1.92^{x}10^{-5}$, $4.88^{x}10^{-5}$]
Residual Variance	0.37(0.02)	[0.33, 0.41]

Note: Based on 224 participants with 1,957 longitudinal records. Duchenne smile was the reference group for facial expression condition.
RSE = robust standard error
*$p \leq .05$
***$p \leq .001$

Contrary to hypotheses, RSA trajectories were not significantly different between the Duchenne smile and grimace conditions ($\hat{\gamma}$ = -0.004, z = -0.70, p = .49; Figure 7) or the Duchenne smile and neutral facial expression conditions ($\hat{\gamma}$ = -0.0006, z = -0.11, p = .91). Furthermore, RSA trajectories were not significantly different between the grimace condition and the neutral facial expression condition ($\hat{\gamma}$ = 0.003, z = 0.59, p = .55). Multiple comparisons confirmed that RSA was not significantly different between any of the conditions at any of the

ten time points.

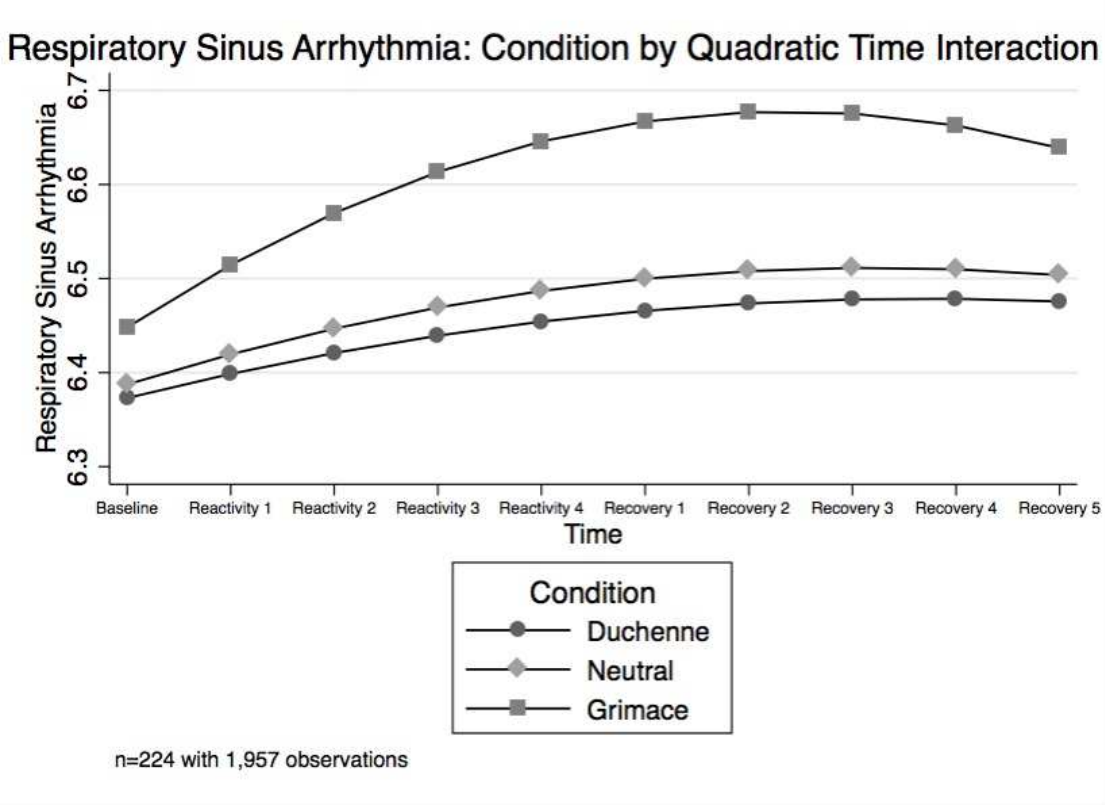

Figure 7. RSA response to the pressure algometer task by condition over time.

Cold pressor. Nine participants were outliers and were dropped from analyses. An unconditional means model showed that 55.65% of the variation in RSA was due to between-person differences and 44.35% of the variation in RSA was due to within-person differences. An unconditional linear growth model showed that there was significant between-person variation in change over time. The final model predicting RSA responses to the cold pressor included age as a covariate and the interaction between the quadratic form of time and facial expression condition. The interaction between condition and quadratic time was not significant ($\chi^2 = 1.60$, $p = .45$); therefore, the quadratic rate of change in RSA was not different across conditions (Table 6).

Table 6. Multilevel between-person effects of the interaction between facial expression condition, time, and quadratic time on rate of change in RSA during the cold pressor.

Variable	Coefficients (RSE)	95% CI
Fixed Effects		
Intercept	6.93(0.32)***	[6.31, 7.54]
Age	-0.04(0.02)*	[-0.07, -0.007]
Time	0.05(0.04)	[-0.03, 0.13]
Condition		
Grimace	0.18(0.15)	[-0.11, 0.47]
Neutral	0.07(0.14)	[-0.20, 0.33]
Condition^{x}time		
Grimace	0.0002(0.05)	[-0.11, 0.11]
Neutral	0.06(0.05)	[-0.05, 0.16]
Condition^{x}time^{x}time		
Grimace	-0.0004 (0.007)	[-0.01, 0.01]
Neutral	-0.007(0.007)	[-0.02, 0.006]
Random Effects	Estimate (RSE)	95% CI
Random Part		
Random Intercept ($\hat{\sigma}_o^2$)	0.59(0.07)	[0.47, 0.73]
Random Slope ($\hat{\sigma}_1^2$)	$7.57^{x}10^{-21}$ ($2.79^{x}10^{-19}$)	[$3.66^{x}10^{-52}$, $1.57^{x}10^{11}$]
Random Quadratic Slope ($\hat{\sigma}_2^2$)	$4.34^{x}10^{-5}$ ($1.02^{x}10^{-5}$)	[$2.73^{x}10^{-5}$, $6.89^{x}10^{-5}$]
Residual Variance	0.48(0.03)	[0.42, 0.54]

Note: Based on 223 participants with 1,758 longitudinal records. Duchenne smile was the reference group for facial expression condition.
RSE = robust standard error
*$p \leq .05$
***$p \leq .001$

Contrary to hypotheses, RSA trajectories were not significantly different between the Duchenne smile and grimace conditions ($\hat{Y}$ = -0.004, z = -0.06, p = .96; Figure 8) or the Duchenne smile and neutral facial expression conditions ($\hat{Y}$ = -0.007, z = -1.08, p = .28). Furthermore, RSA trajectories were not significantly different between the grimace condition and the neutral facial expression condition ($\hat{Y}$ = -0.007, z = -1.07, p = .29). Multiple comparisons

confirmed that RSA was not significantly different between any of the conditions at any of the ten time points.

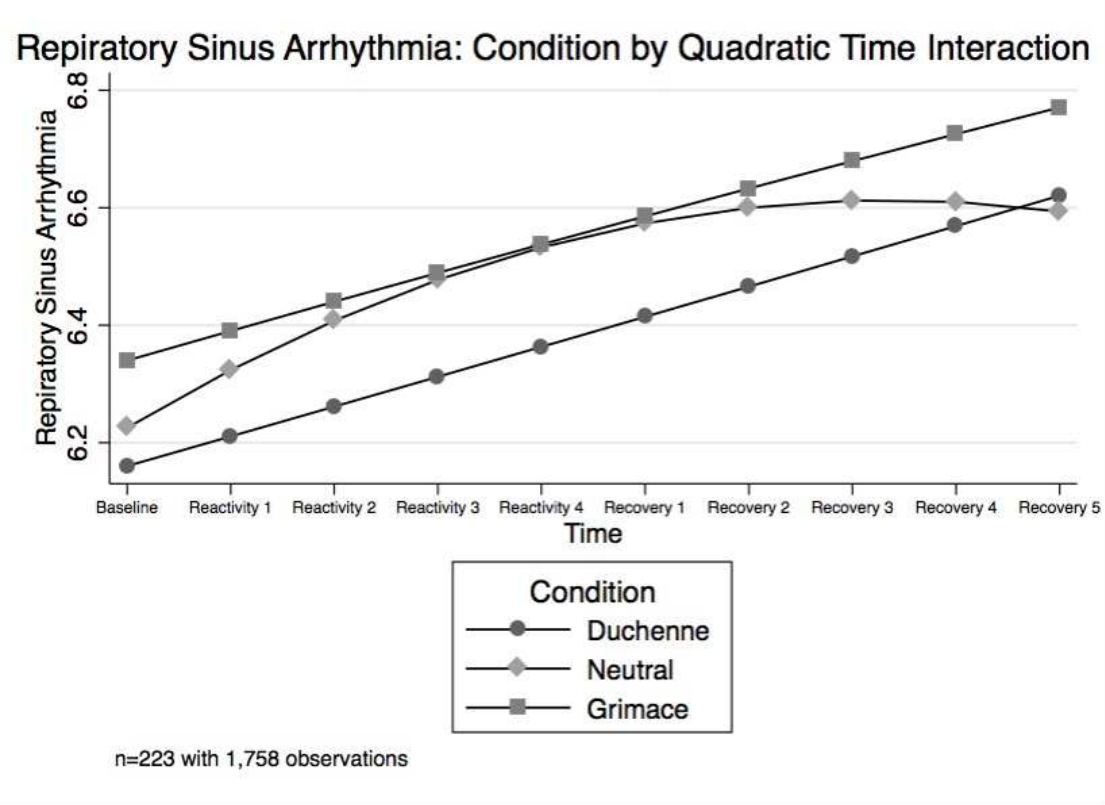

Figure 8. RSA response to the cold pressor by condition over time.

PEP. The means, standard deviations, and ranges of PEP during baseline, reactivity (for both pain tasks), and recovery (for both pain tasks) are reported in Table 7.

Table 7. Descriptive statistics for PEP during baseline, reactivity, and recovery for each pain task and each condition.

	Time														
	Baseline			Reactivity (algometer task)			Recovery (algometer task)			Reactivity (cold pressor)			Recovery (cold pressor)		
Condition	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*
Duchenne smile	108.04	7.39	82.00-121.20	106.47	8.58	76.00-119.00	107.34	7.26	82.80-119.60	106.26	9.57	70.00-119.00	107.42	7.00	82.00-119.20
Grimace	106.78	8.54	75.60-120.40	105.66	8.75	74.00-121.33	106.28	8.34	75.20-119.60	104.67	10.22	65.00-120.00	106.56	7.91	78.80-120.40
Neutral facial expression	108.68	7.30	88.00-122.80	106.44	9.50	75.00-122.00	107.57	8.23	79.20-122.00	104.87	11.25	66.00-107.21	107.21	8.16	78.80-121.60

Pressure algometer task. Twelve participants were outliers and were dropped from analyses. An unconditional means model showed that 77.85% of the variation in PEP was due to between-person differences and 22.15% of the variation in PEP was due to within-person differences. An unconditional linear growth model showed that there was significant between-person variation in change over time. No covariates significantly improved the model fit, so none were included in the final model. The final model predicting PEP responses to the pressure algometer task included the interaction between the quadratic form of time and facial expression condition. The interaction between condition and quadratic time was not significant ($\chi^2 = 0.64$, $p = .73$); therefore, the quadratic rate of change in RSA was not different across conditions (Table 8).

Table 8. Multilevel between-person effects of the interaction between facial expression condition, time, and quadratic time on rate of change in PEP during the pressure algometer task.

Variable	Coefficients (RSE)	95% CI
Fixed Effects		
Intercept	107.58(0.99)***	[105.63, 109.52]
Time	-0.99(0.21)***	[-1.41, -0.57]
Condition		
Grimace	-0.78(1.36)	[-3.45, 1.89]
Neutral	-0.17(1.45)	[-3.02, 2.68]
Condition^{x}time		
Grimace	0.16(0.30)	[-0.43, 0.75]
Neutral	0.28(0.29)	[-0.28, 0.84]
Condition^{x}time^{x}time		
Grimace	-0.02(0.04)	[-0.09, 0.06]
Neutral	-0.03(0.04)	[-0.10, 0.04]
Random Effects	Estimate (RSE)	95% CI
Random Part		
Random Intercept ($\hat{\sigma}_o^2$)	60.19(7.98)	[46.41, 78.06]
Random Slope ($\hat{\sigma}_1^2$)	$6.26^{x}10^{-11}$ ($1.89^{x}10^{-9}$)	[$1.49^{x}10^{-36}$, $2.63^{x}10^{15}$]
Random Quadratic Slope ($\hat{\sigma}_2^2$)	.002(.0009)	[0.009, 0.005]
Residual Variance	16.69(4.67)	[9.66, 28.87]

Note: Based on 192 participants with 1,685 longitudinal records. Duchenne smile was the reference group for facial expression condition.
RSE = robust standard error
***$p \leq .001$

Contrary to hypotheses, PEP trajectories were not significantly different between the Duchenne smile and grimace conditions (Υ = -0.02, z = -0.45, p = .66; Figure 9) or the Duchenne smile and neutral facial expression conditions (Υ = -0.03, z = -0.80, p = .42). Furthermore, PEP trajectories were not significantly different between the grimace condition and the neutral facial expression condition (Υ = -0.01, z = -0.37, p = .71). Multiple comparisons confirmed that PEP was not significantly different between any of the conditions at any of the ten time points.

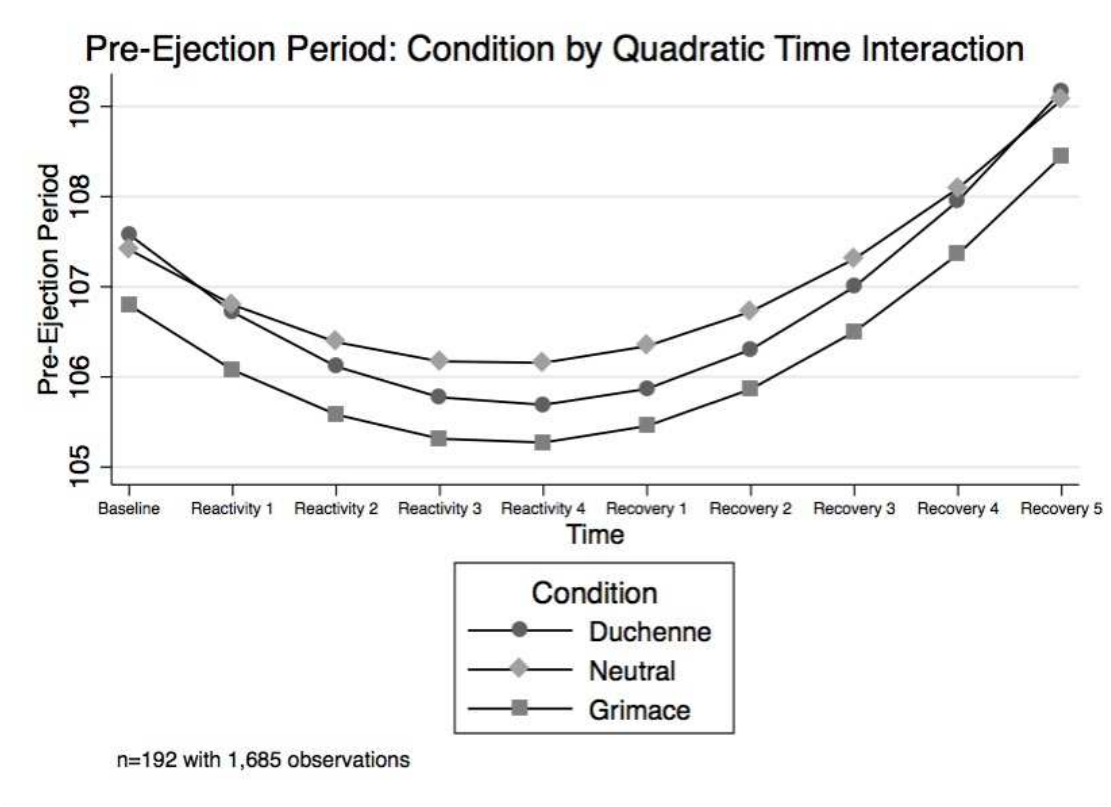

Figure 9. PEP response to the pressure algometer task by condition over time.

Cold pressor. Eleven participants were outliers and were dropped from analyses. An unconditional means model showed that 73.74% of the variation in PEP was due to between-person differences and 26.26% of the variation in PEP was due to within-person differences. An unconditional linear growth model showed that there was significant between-person variation in change over time. The final model predicting PEP responses to the cold pressor included drinks per week and BMI as covariates and the interaction between the quadratic form of time and facial expression condition. The interaction between condition and quadratic time was not significant ($\chi^2 = 3.82$, $p = .15$); therefore, the quadratic rate of change in PEP was not different across conditions (Table 9).

Table 9. Multilevel between-person effects of the interaction between facial expression condition, time, and quadratic time on rate of change in PEP during the cold pressor.

Variable	Coefficients (RSE)	95% CI
Fixed Effects		
Intercept	116.37(3.84)***	[108.85, 123.89]
BMI	-0.40(0.15)**	[-0.71, -0.10]
Drinks per week	0.51(0.19)**	[0.13, 0.88]
Time	-0.67(0.23)**	[-1.13, -0.21]
Condition		
Grimace	-1.69(1.52)	[-4.66, 1.28]
Neutral	0.41(1.51)	[-2.54, 3.37]
Condition^{x}time		
Grimace	0.14(0.31)	[-0.47, 0.75]
Neutral	-0.70(0.38)	[-1.44, 0.04]
Condition^{x}time^{x}time		
Grimace	-0.007(0.04)	[-0.08, 0.07]
Neutral	0.07(0.04)	[-0.02, 0.16]
Random Effects	Estimate (RSE)	95% CI
Random Part		
Random Intercept ($\hat{\sigma}_o^2$)	56.29(7.05)	[44.04, 71.96]
Random Slope ($\hat{\sigma}_1^2$)	$2.15^{x}10^{-11}$ ($6.01^{x}10^{-10}$)	[$3.40^{x}10^{-35}$, $1.36^{x}10^{13}$]
Random Quadratic Slope ($\hat{\sigma}_2^2$)	0.003(0.001)	[0.001, 0.008]
Residual Variance	21.25(4.81)	[13.63, 33.11]

Note: Based on 191 participants with 1,512 longitudinal records. Duchenne smile was the reference group for facial expression condition.
RSE = robust standard error
**$p \leq .01$
***$p \leq .001$

Contrary to hypotheses, PEP trajectories were not significantly different between the Duchenne smile and grimace conditions ($\hat{\gamma}$ = -0.007, z = -0.18, p = .86; Figure 10) or the Duchenne smile and neutral facial expression conditions ($\hat{\gamma}$ = 0.07, z = 1.61, p = .11). Furthermore, PEP trajectories were not significantly different between the grimace condition and the neutral facial expression condition ($\hat{\gamma}$ = 0.08, z = 1.88, p = .06). Multiple comparisons

confirmed that PEP was not significantly different between any of the conditions at any of the ten time points.

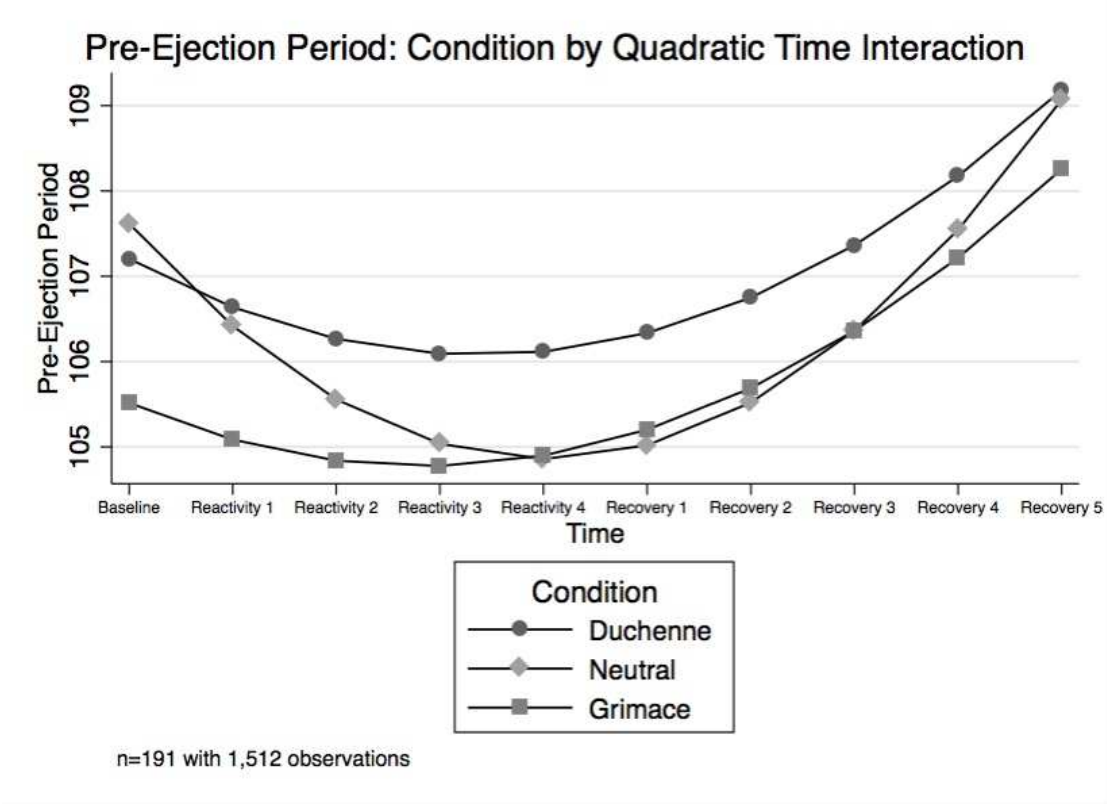

Figure 10. PEP response to the cold pressor by condition over time.

Pain threshold. The means, standard deviations, and ranges of pain threshold during the pressure algometer task and cold pressor are reported in Table 10.

Table 10. Descriptive statistics for pain threshold during the pressure algometer task and cold pressor for each condition.

	Pain Task								
	Pressure Algometer (pressure in kPa)			Pressure Algometer (time in seconds)			Cold Pressor (time in seconds)		
Condition	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*
Duchenne smile	413.88	238.10	95.00-968.40	92.79	49.54	21.00-193.00	25.70	20.71	5.00-103.00
Grimace	408.16	233.52	40.26-1027.04	85.14	44.64	5.00-210.00	22.62	18.00	3.00-106.00
Neutral facial expression	435.70	244.34	83.00-1057.42	91.33	54.09	17.00-238.00	23.50	19.20	1.00-93.00

Pressure algometer task.

Time. One participant was an outlier and was excluded from analyses. Sex, trait PA, and the Stoic-Reticence and Stoic-Superiority subscales of the Pain Attitudes Questionnaire, Revised (Yong et al., 2003), were included as covariates in linear regression analyses. Contrary to hypotheses, threshold time during the pressure algometer task was not significantly different between the Duchenne smile and grimace conditions (B = -7.13, SE = 8.16, t = -0.87, p = .38) or between the Duchenne smile and neutral facial expression conditions (B = -2.01, SE = 8.95, t = -0.22, p = .82). Threshold time during the pressure algometer task was also not significantly different between the grimace and neutral facial expression conditions (B = 4.38, SE = 8.59, t = 0.51, p = .61).

Pressure. The Stoic-Reticence and Stoic-Superiority subscales of the Pain Attitudes Questionnaire, Revised (Yong et al., 2003), were included as covariates in linear regression

analyses. Contrary to hypotheses, threshold pressure during the pressure algometer task was not significantly different between the Duchenne smile and grimace conditions (B = -4.62, SE = 42.20, t = -0.11, p = .91) or between the Duchenne smile and neutral facial expression conditions (B = 30.12, SE = 42.64, t = 0.71, p = .48). Threshold pressure during the pressure algometer task was also not significantly different between the grimace and neutral facial expression conditions (B = 29.26, SE = 43.56, t = 0.67, p = .50).

Cold pressor. Four participants were outliers and were excluded from analyses. The Stoic-Reticence and Stoic-Superiority subscales of the Pain Attitudes Questionnaire, Revised (Yong et al., 2003), were included as covariates in linear regression analyses. In line with hypotheses, threshold time during the cold pressor was significantly higher for participants in the Duchenne smile condition than for participants in the grimace condition (B = -14.13, SE = 6.25, t = -2.26, p = .03). Threshold time during the cold pressor was not significantly different between the Duchenne smile and neutral facial expression conditions (B = -7.97, SE = 7.10, t = -1.12, p = .26) or between the grimace and neutral facial expression conditions (B = 1.61, SE = 3.27, t = 0.49, p = .62).

Pain tolerance. The means, standard deviations, and ranges of pain tolerance during the pressure algometer task and cold pressor are reported in Table 11.

Table 11. Descriptive statistics for pain tolerance during the pressure algometer task and cold pressor for each condition.

	Pain Task								
	Pressure Algometer (pressure in kPa)			Pressure Algometer (time in seconds)			Cold Pressor (time in seconds)		
Condition	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*
Duchenne smile	664.54	247.18	50.00-1200.00	149.09	51.54	49.00-240.00	105.12	89.71	8.00-240.00
Grimace	663.96	222.03	206.80-1186.78	137.11	51.78	12.00-240.00	95.16	90.53	12.00-240.00
Neutral facial expression	659.78	249.57	106.82-1213.24	144.05	53.98	43.00-240.00	82.27	80.78	6.00-240.00

Pressure algometer task.

Time. Two participants were outliers and were excluded from analyses. Sex, BMI, average stress, trait PA, and the Stoic-Reticence, Stoic-Superiority, and Cautious-Reticence subscales of the Pain Attitudes Questionnaire, Revised (Yong et al., 2003), were included as covariates in linear regression analyses. Tolerance time during the pressure algometer task was higher for participants in the Duchenne smile condition than for participants in the grimace condition, although this was only marginally significant (B = -13.71, SE = 7.96, t = -1.72, p = .09). Tolerance time was not significantly different between the Duchenne smile and neutral facial expression conditions (B = -2.90, SE = 8.14, t = -0.36, p = .72) or the grimace and neutral facial expression conditions (B = 7.13, SE = 8.54, t = 0.83, p = .41).

Pressure. One participant was an outlier and was excluded from analyses. Drinks per week was included as a covariate in linear regression analyses. Contrary to hypotheses, tolerance

pressure during the pressure algometer task was not significantly different between the Duchenne smile and grimace conditions (B = -0.33, SE = 40.72, t = -0.01, p = .99) or between the Duchenne smile and neutral facial expression conditions (B = -0.63, SE = 40.65, t = -0.02, p = .99). Tolerance pressure during the pressure algometer task was also not significantly different between the grimace and neutral facial expression conditions (B = -10.13, SE = 40.68, t = -0.25, p = .80).

Cold pressor. One participant was an outlier and was excluded from analyses. Ethnicity, BMI, exercise, and the Stoic-Reticence and Stoic-Superiority subscales of the Pain Attitudes Questionnaire, Revised (Yong et al., 2003), were included as covariates in linear regression analyses. Contrary to hypotheses, tolerance time during the cold pressor was not significantly different between the Duchenne smile and grimace conditions (B = -12.01, SE = 14.06, t = -0.85, p = .39) or between the Duchenne smile and neutral facial expression conditions (B = -19.65, SE = 12.97, t = -1.51, p = .13). Tolerance time during the cold pressor was also not significantly different between the grimace and neutral facial expression conditions (B = -11.28, SE = 13.46, t = -0.84, p = .40).

Self-reported pain.

Pressure algometer task. Seven participants were outliers and were excluded from analyses. Pain catastrophizing was included as a covariate in linear regression analyses. Contrary to hypotheses, self-reported pain change scores were higher for participants in the Duchenne smile condition than participants in the grimace condition, although this was only marginally significant (B = -5.19, SE = 3.16, t = -1.64, p = .10). Self-reported pain change scores were not significantly different between the Duchenne smile and neutral facial expression conditions (B =

-1.21, SE = 2.95, t = -0.41, p = .68) or the grimace and neutral facial expression conditions (B = 4.52, SE = 3.09, t = 1.46, p = .15).

Cold pressor. Five participants were outliers and were excluded from analyses. Ethnicity was included as a covariate in linear regression analyses. Contrary to hypotheses, self-reported pain change scores were not significantly different between the Duchenne smile and grimace conditions (B = -5.97, SE = 3.97, t = -1.50, p = .13) or between the Duchenne smile and neutral facial expression conditions (B = 0.22, SE = 4.26, t = 0.05, p = .96). Self-reported pain change scores were higher for individuals in the grimace condition as compared with individuals in the neutral facial expression conditions, although this was only marginally significant (B = 7.25, SE = 4.30, t = 1.69, p = .10).

Mediation analyses. As described in the Data Analysis section, there were two mediators of interest in this study: PA and orbicularis oculi activation. Seemingly unrelated regressions were conducted to determine whether PA mediated the relationship between smiling and cardiovascular outcome variables of interest (HR, RSA, and PEP) during reactivity and recovery. Seemingly unrelated regressions were also conducted to determine whether PA mediated the relationship between smiling and self-reported pain and whether orbicularis oculi activation mediated the relationship between smiling and RSA. The same outliers from main analyses were excluded from mediation analyses. Below, I test the path from the independent variable to the mediator; the path from the mediator to the dependent variable; and the path from the independent variable to the dependent variable, controlling for the mediator. I also test the overall indirect effect coefficient to determine whether each mediational hypothesis is supported.

PA. Average change in state PA during the pressure algometer task was -7.10 for the Duchenne smile condition; -10.73 for the grimace condition; and -12.93 for the neutral facial

expression condition; thus, PA was higher during baseline than during the task. These changes in state PA were different among facial expression conditions, $F(2, 218) = 2.86$, $p = .06$, although this was only marginally significant. A Bonferroni post-hoc analysis revealed that the difference in change in state PA between the Duchenne smile and neutral facial expression conditions was marginally significant ($p = .06$); individuals in the Duchenne smile condition reported higher levels of PA during the pressure algometer task than individuals in the neutral facial expression condition. Average change in state PA during the cold pressor was -19.34 for the Duchenne smile condition; -17.68 for the grimace condition; and -22.41 for the neutral facial expression condition; thus, PA was higher during baseline than during the task. These changes in state PA were not significantly different among facial expression conditions, $F(2, 216) = 0.96$, $p = .39$.

HR reactivity. Smiling during the pressure algometer task was significantly associated with change in PA such that, on average, individuals who were randomly assigned to make Duchenne smiles had PA change scores that were 6.06 points higher than individuals who were randomly assigned to make neutral facial expressions ($B = -6.06$, SE = 2.74, $z = -2.21$, $p = .03$; Figure 11). In other words, individuals who were making Duchenne smiles decreased in PA *less* during the task than individuals who were making neutral facial expressions. PA change scores were not significantly associated with HR reactivity during the pressure algometer task ($B = -0.05$, SE = 0.03, $z = -1.34$, $p = .18$). After controlling for change in PA, smiling was not a significant predictor of HR reactivity during the pressure algometer task ($B = -0.0005$, SE = 1.14, $z = 0.00$, $p = 1.00$). The indirect effect coefficient was not significant ($B = 0.28$, SE = 0.24, $z = 1.14$, $p = .25$). Therefore, these results do not support the mediational hypothesis that change in PA would mediate the relationship between Duchenne smiling and HR reactivity during the pressure algometer task.

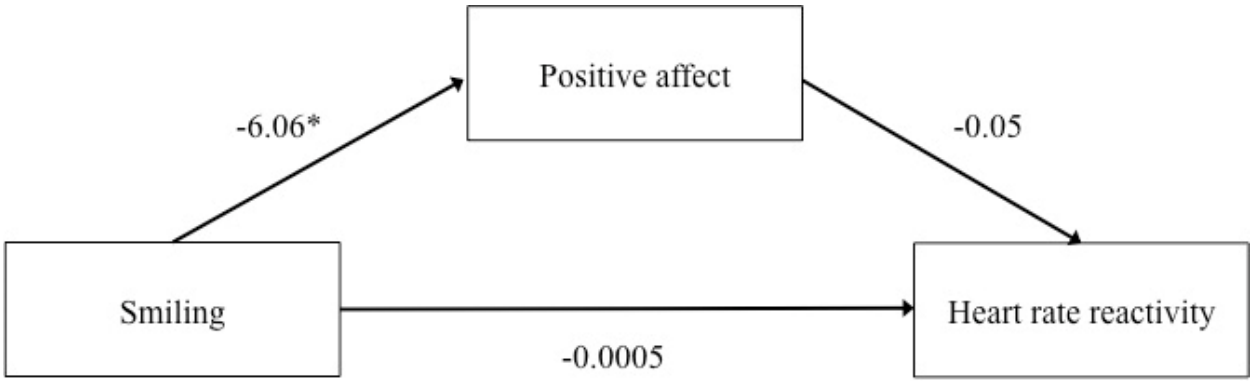

Figure 11. Unstandardized regression coefficients for the relationship between smiling and HR reactivity during the pressure algometer task as mediated by change in PA.

*$p \leq .05$

Smiling during the cold pressor was not significantly associated with change in PA (B = -3.36, SE = 3.69, z = -0.91, p = .36). PA change scores were not significantly associated with HR reactivity during the cold pressor (B = -0.02, SE = 0.03, z = -0.59, p = .56). After controlling for change in PA, smiling was not a significant predictor of HR reactivity during the cold pressor (B = 2.44, SE = 1.48, z = 1.65, p = .10), although this relationship was in the hypothesized direction (smiling was a predictor of lower HR reactivity). The indirect effect coefficient was not significant (B = 0.07, SE = 0.13, z = 0.49, p = .62). Therefore, these results do not support the mediational hypothesis that change in PA would mediate the relationship between Duchenne smiling and HR reactivity during the cold pressor.

HR recovery. Smiling during the pressure algometer task was significantly associated with change in PA such that, on average, individuals who were randomly assigned to make Duchenne smiles had PA change scores that were 6.10 points higher than individuals who were randomly assigned to make neutral facial expressions (B = -6.10, SE = 2.72, z = -2.24, p = .03; Figure 12). In other words, individuals who were making Duchenne smiles decreased in PA *less* during the task than individuals who were making neutral facial expressions. PA change scores

were not significantly associated with HR recovery following the pressure algometer task (B = -0.02, SE = 0.02, z = -1.10, p = .27). After controlling for change in PA, smiling was not a significant predictor of HR recovery following the pressure algometer task (B = 0.03, SE = 0.60 z = 0.04, p = .97). The indirect effect coefficient was not significant (B = 0.12, SE = 0.12, z = 0.99, p = .32). Therefore, these results do not support the mediational hypothesis that change in PA would mediate the relationship between Duchenne smiling and HR recovery following the pressure algometer task.

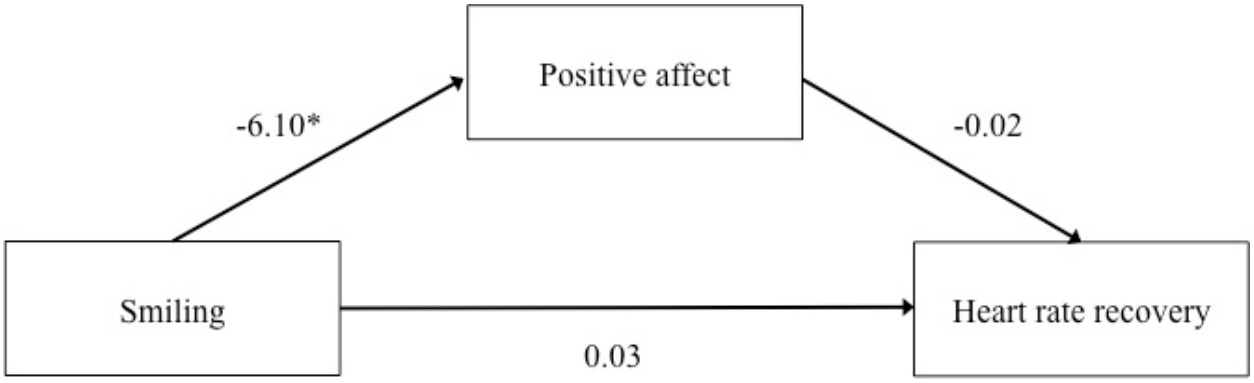

Figure 12. Unstandardized regression coefficients for the relationship between smiling and HR recovery following the pressure algometer task as mediated by change in PA.

*$p \leq .05$

Smiling during the cold pressor was not significantly associated with change in PA (B = -3.36, SE = 3.69, z = -0.91, p = .36). PA change scores were not significantly associated with HR recovery following the cold pressor (B = 0.01, SE = 0.02, z = 0.79, p = .43). After controlling for change in PA, smiling was not a significant predictor of HR recovery following the cold pressor (B = 0.09, SE = 0.68, z = 0.14, p = .89). The indirect effect coefficient was not significant (B = -0.04, SE = 0.07, z = -0.60, p = .55). Therefore, these results do not support the mediational hypothesis that change in PA would mediate the relationship between Duchenne smiling and HR recovery following the cold pressor.

RSA reactivity. Smiling during the pressure algometer task was significantly associated with change in PA such that, on average, individuals who were randomly assigned to make Duchenne smiles had PA change scores that were 6.17 points higher than individuals who were randomly assigned to make neutral facial expressions (B = -6.17, SE = 2.71, z = -2.28, p = .02; Figure 13). In other words, individuals who were making Duchenne smiles decreased in PA *less* during the task than individuals who were making neutral facial expressions. PA change scores were not significantly associated with RSA reactivity during the pressure algometer task (B = 0.005, SE = 0.004, z = 1.11, p = .27). After controlling for change in PA, smiling was not a significant predictor of RSA reactivity during the pressure algometer task (B = 0.04, SE = 1.47, z = 0.25, p = .81). The indirect effect coefficient was not significant (B = -0.03, SE = 0.03, z = -1.00, p = .32). Therefore, these results do not support the mediational hypothesis that change in PA would mediate the relationship between Duchenne smiling and RSA reactivity during the pressure algometer task.

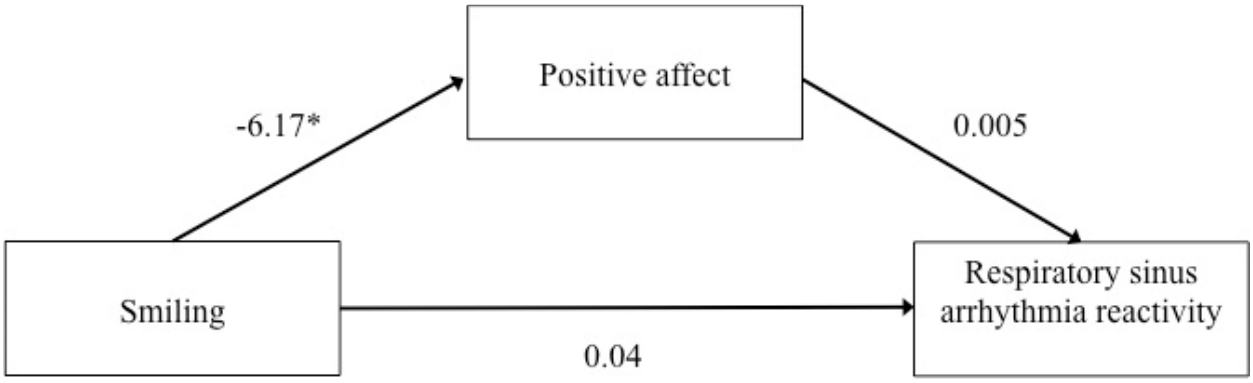

Figure 13. Unstandardized regression coefficients for the relationship between smiling and RSA reactivity during the pressure algometer task as mediated by change in PA.

*$p \leq .05$

Smiling during the cold pressor was not significantly associated with change in PA (B =

-3.71, SE = 3.69, z = -1.01, p = .32). PA change scores were not significantly associated with RSA reactivity during the cold pressor (B = -0.0007, SE = 0.004, z = -0.18, p = .86). After controlling for change in PA, smiling was not a significant predictor of RSA reactivity during the cold pressor (B = -0.07, SE = 0.17, z = -0.38, p = .71). The indirect effect coefficient was not significant (B = 0.002, SE = 0.01, z = 0.18, p = .86). Therefore, these results do not support the mediational hypothesis that change in PA would mediate the relationship between Duchenne smiling and RSA reactivity during the cold pressor.

RSA recovery. Smiling during the pressure algometer task was significantly associated with change in PA such that, on average, individuals who were randomly assigned to make Duchenne smiles had PA change scores that were 5.97 points higher than individuals who were randomly assigned to make neutral facial expressions (B = -5.97, SE = 2.70, z = -2.22, p = .03; Figure 14). In other words, individuals who were making Duchenne smiles decreased in PA *less* during the task than individuals who were making neutral facial expressions. PA change scores were not significantly associated with RSA recovery following the pressure algometer task (B = -0.001, SE = 0.003, z = -0.42, p = .67). After controlling for change in PA, smiling was not a significant predictor of RSA recovery following the pressure algometer task (B = 0.03, SE = 0.08, z = 0.36, p = .72). The indirect effect coefficient was not significant (B = 0.01, SE = 0.02, z = 0.42, p = .68). Therefore, these results do not support the mediational hypothesis that change in PA would mediate the relationship between Duchenne smiling and RSA recovery from the pressure algometer task.

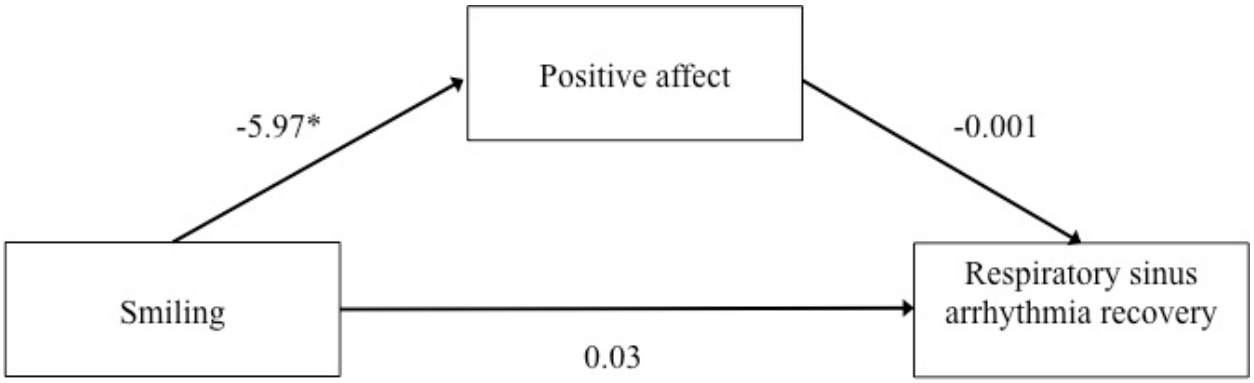

Figure 14. Unstandardized regression coefficients for the relationship between smiling and RSA recovery following the pressure algometer task as mediated by change in PA.

*$p \leq .05$

Smiling during the cold pressor was not significantly associated with change in PA (B = -3.29, SE = 3.69, z = -0.89, p = .37). PA change scores were not significantly associated with RSA recovery following the cold pressor (B = -0.003, SE = 0.002, z = -1.57, p = .12). After controlling for change in PA, smiling was not a significant predictor of RSA recovery following the cold pressor (B = -0.03, SE = 0.10, z = -0.36, p = .72). The indirect effect coefficient was not significant (B = 0.01, SE = 0.01, z = 0.78, p = .44). Therefore, these results do not support the mediational hypothesis that change in PA would mediate the relationship between Duchenne smiling and RSA recovery following the cold pressor.

PEP reactivity. Smiling during the pressure algometer task was significantly associated with change in PA such that, on average, individuals who were randomly assigned to make Duchenne smiles had PA change scores that were 6.74 points higher than individuals who were randomly assigned to make neutral facial expressions (B = -6.74, SE = 2.87, z = -2.35, p = .02; Figure 15). In other words, individuals who were making Duchenne smiles decreased in PA *less* during the task than individuals who were making neutral facial expressions. PA change scores were not significantly associated with PEP reactivity during the pressure algometer task (B =

-0.02, SE = 0.04, z = -0.52, p = .61). After controlling for change in PA, smiling was not a significant predictor of PEP reactivity during the pressure algometer task (B = -0.98, SE = 1.38, z = -0.71, p = .48). The indirect effect coefficient was not significant (B = 0.15, SE = 0.29, z = 0.51, p = .61). Therefore, these results do not support the mediational hypothesis that change in PA would mediate the relationship between Duchenne smiling and PEP reactivity during the pressure algometer task.

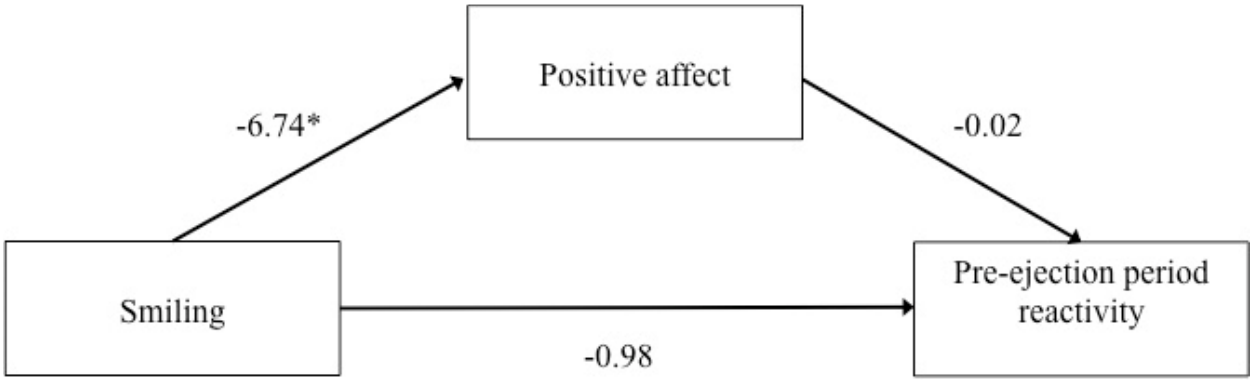

Figure 15. Unstandardized regression coefficients for the relationship between smiling and PEP reactivity during the pressure algometer task as mediated by change in PA.

*$p \leq .05$

Smiling during the cold pressor was not significantly associated with change in PA (B = -3.61, SE = 4.04, z = -0.89, p = .37). PA change scores were not significantly associated with PEP reactivity during the cold pressor (B = 0.03, SE = 0.03, z = 0.98, p = .33). After controlling for PA, smiling was not a significant predictor of PEP reactivity during the cold pressor (B = -1.04, SE = 1.30, z = -0.80, p = .42). The indirect effect coefficient was not significant (B = -0.10, SE = 0.15, z = -0.66, p = .51). Therefore, these results do not support the mediational hypothesis that change in PA would mediate the relationship between Duchenne smiling and PEP reactivity during the cold pressor.

PEP recovery. Smiling during the pressure algometer task was significantly associated with change in PA such that, on average, individuals who were randomly assigned to make Duchenne smiles had PA change scores that were 6.79 points higher than individuals who were randomly assigned to make neutral facial expressions (B = -6.79, SE = 2.85, z = -2.38, p = .02; Figure 16). In other words, individuals who were making Duchenne smiles decreased in PA *less* during the task than individuals who were making neutral facial expressions. PA change scores were not significantly associated with PEP recovery following the pressure algometer task (B = -0.003, SE = 0.02, z = -0.18, p = .86). After controlling for change in PA, smiling was not a significant predictor of PEP recovery following the pressure algometer task (B = -0.44, SE = 0.50, z = -0.89, p = .37). The indirect effect coefficient was not significant (B = 0.02, SE = 0.10, z = 0.18, p = .86). Therefore, these results do not support the mediational hypothesis that change in PA would mediate the relationship between Duchenne smiling and PEP recovery following the pressure algometer task.

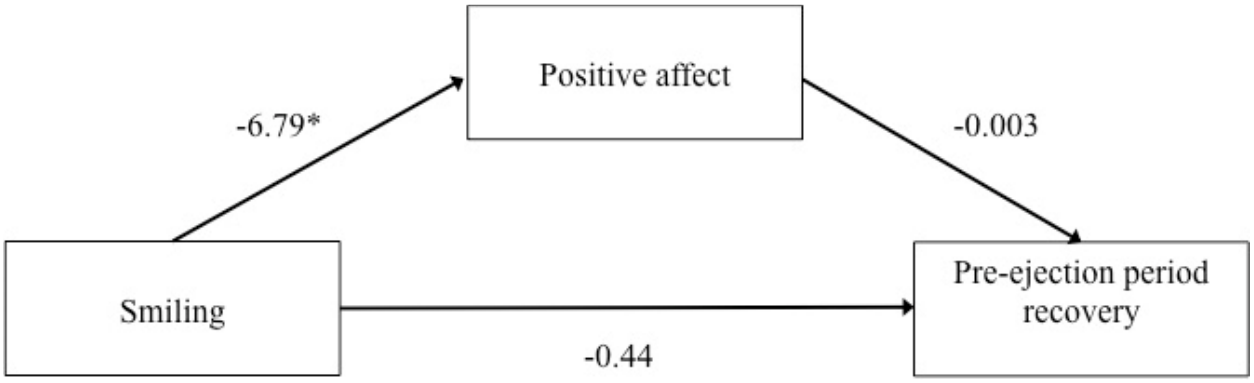

Figure 16. Unstandardized regression coefficients for the relationship between smiling and PEP recovery following the pressure algometer task as mediated by change in PA.

*$p \leq .05$

Smiling during the cold pressor was not significantly associated with change in PA (B =

-3.61, SE = 4.04, z = -0.89, p = .37). In line with hypotheses, PA change scores were significantly associated with PEP recovery following the cold pressor such that greater change in PA was connected to higher PEP during recovery (B = 0.03, SE = 0.02, z = 2.11, p = .04; Figure 17). In other words, higher levels of PA during the cold pressor were associated with *lower* levels of sympathetic nervous system activation. After controlling for change in PA, smiling was a marginally significant predictor of PEP recovery following the cold pressor (B = -1.35, SE = 0.73, z = -1.84, p = .07). This relationship was in the hypothesized direction – smiling was connected with higher levels of PEP (lower levels of sympathetic nervous system activation) during recovery. The indirect effect coefficient was not significant (B = -0.12, SE = 0.15, z = -0.82, p = .41). Therefore, these results do not support the mediational hypothesis that change in PA would mediate the relationship between Duchenne smiling and PEP recovery following the cold pressor.

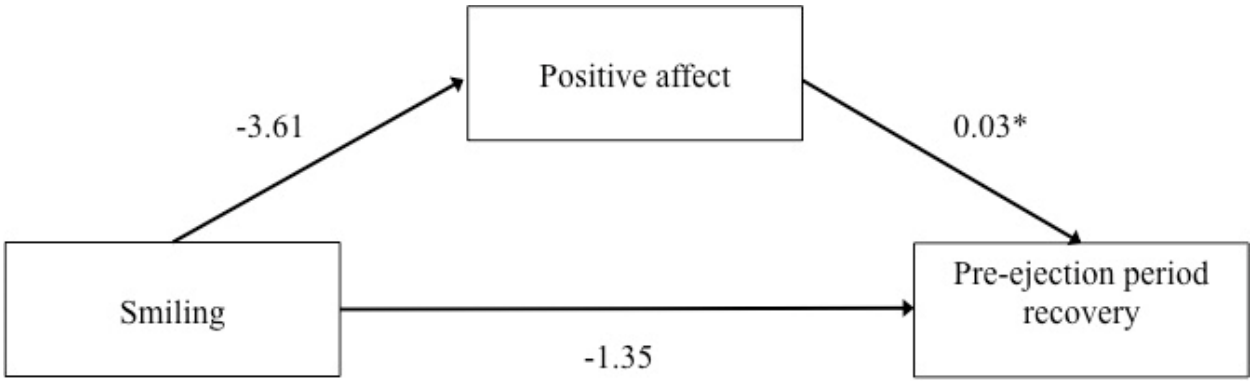

Figure 17. Unstandardized regression coefficients for the relationship between smiling and PEP recovery during the cold pressor as mediated by change in PA.

*$p \leq .05$

Self-reported pain. PA marginally significantly fully mediated the relationship between smiling during the pressure algometer task and change in self-reported pain. Smiling during the

pressure algometer task was significantly associated with change in PA such that, on average, individuals who were randomly assigned to make Duchenne smiles had PA change scores that were 7.08 points higher than individuals who were randomly assigned to make neutral facial expressions (B = -7.08, SE = 3.30, z = -2.15, p = .03; Figure 18). In other words, individuals who were making Duchenne smiles decreased in PA *less* than individuals who were making neutral facial expressions. PA change scores were significantly associated with change in self-reported pain during the pressure algometer task (B = -0.28, SE = 0.09, z = -3.24, p = .001) such that, on average, for every one-point increase in PA change score, self-reported pain change scores decreased by .28. Thus, individuals who reported higher PA during the pressure algometer task also reported less pain during the pressure algometer task. After controlling for change in PA, smiling was not a significant predictor of change in self-reported pain during the pressure algometer task (B = -2.33, SE = 2.96, z = -0.79, p = .43). The indirect effect coefficient was marginally significant (B = 1.95, SE = 1.09, z = 1.79, p = .07), meaning that change in PA explained a marginally significant amount of variation in the relationship between smiling and change in self-reported pain. Therefore, these results somewhat support the mediational hypothesis that change in PA would mediate the relationship between Duchenne smiling and change in self-reported pain during the pressure algometer task.

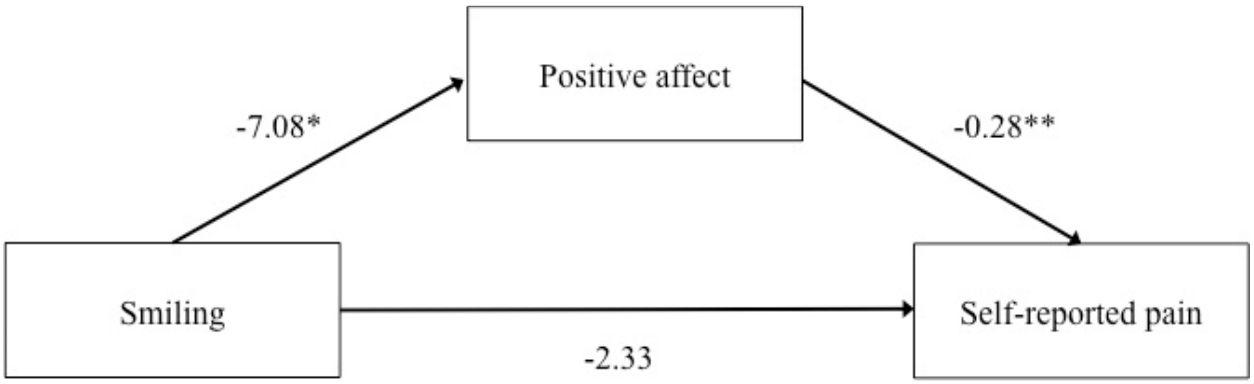

Figure 18. Unstandardized regression coefficients for the relationship between smiling and change in self-reported pain during the pressure algometer task as mediated by change in PA. *$p \leq .05$, ** $p \leq .01$

Smiling during the cold pressor was not significantly associated with change in PA (B = -1.29, SE = 4.69, z = -0.28, p = .78). PA change scores were significantly associated with change in self-reported pain during the cold pressor (B = -0.28, SE = 0.08, z = -3.43, p = .001; Figure 19) such that, on average, for every one-point increase in PA change score, self-reported pain change scores decreased by .28. Thus, individuals who reported higher PA during the cold pressor also reported less pain during the cold pressor. After controlling for change in PA, smiling was not a significant predictor of change in self-reported pain during the cold pressor (B = -0.74, SE = 3.94, z = -0.19, p = .85). The indirect effect coefficient was not significant (B = 0.37, SE = 1.34, z = 0.27, p = .78). Therefore, these results do not support the mediational hypothesis that change in PA would mediate the relationship between Duchenne smiling and change in self-reported pain during the cold pressor.

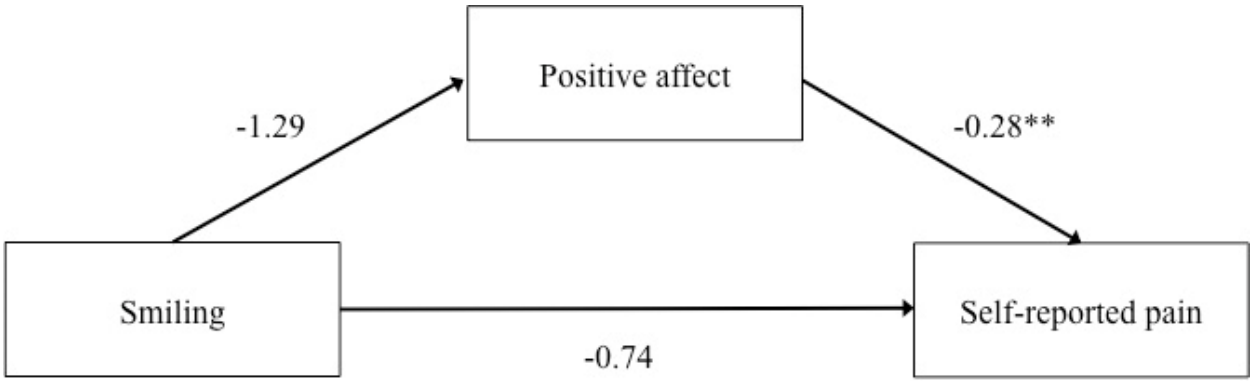

Figure 19. Unstandardized regression coefficients for the relationship between smiling and change in self-reported pain during the cold pressor as mediated by change in PA.

** $p \leq .01$

Orbicularis oculi activation and RSA. In addition to the excluded RSA outliers from main analyses, five participants had orbicularis oculi activation change scores for the pressure algometer task that were outliers and six participants had orbicularis oculi activation change scores for the cold pressor. These orbicularis oculi activation change score outliers were excluded from their respective mediation analyses.

RSA reactivity. Smiling during the pressure algometer task was significantly associated with change in orbicularis oculi activation such that, on average, individuals who were randomly assigned to make Duchenne smiles had orbicularis oculi activation change scores that were 6.18 hertz (Hz) higher than individuals who were randomly assigned to make neutral facial expressions (B = -6.18, SE = 0.72, z = -8.53, $p < .001$; Figure 20). In other words, individuals who were making Duchenne smiles increased more in orbicularis oculi activation during the pressure algometer task compared with baseline than individuals who were making neutral facial expressions. Orbicularis oculi activation change scores were not significantly associated with RSA reactivity during the pressure algometer task (B = 0.01, SE = 0.02, z = 0.85, p = .40). After controlling for change in orbicularis oculi activation, smiling was not a significant predictor of

RSA reactivity during the pressure algometer task (B = 0.11, SE = 0.17, z = 0.65, p = .52). The indirect effect coefficient was not significant (B = -0.09, SE = 0.10, z = -0.85, p = .40). Therefore, these results do not support the mediational hypothesis that change in orbicularis oculi activation would mediate the relationship between Duchenne smiling and RSA reactivity during the pressure algometer task.

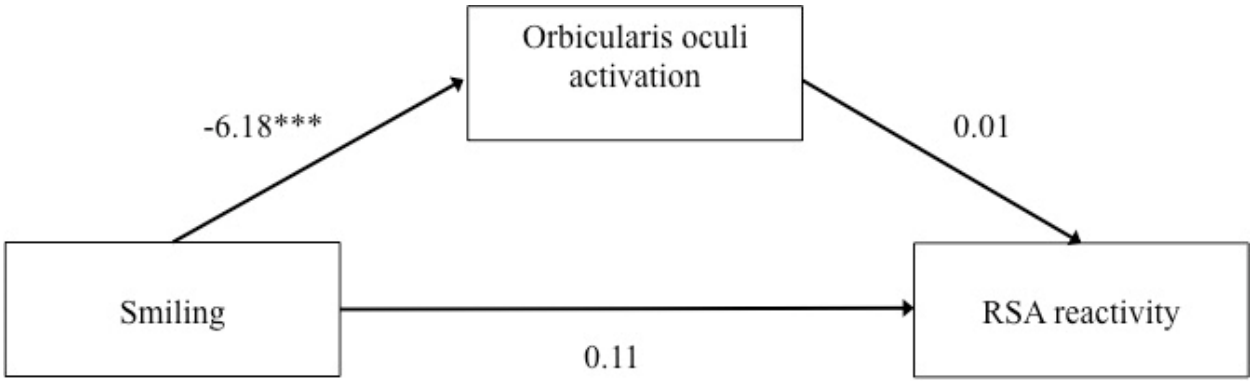

Figure 20. Unstandardized regression coefficients for the relationship between smiling and RSA reactivity during the pressure algometer task as mediated by change in orbicularis oculi activation.

*** $p \leq .001$

Smiling during the cold pressor was significantly associated with change in orbicularis oculi activation such that, on average, individuals who were randomly assigned to make Duchenne smiles had orbicularis oculi activation change scores that were 7.00 Hz higher than individuals who were randomly assigned to make neutral facial expressions (B = -7.00, SE = 2.96, z = -2.37, p =.02; Figure 21). Orbicularis oculi activation change scores were not significantly associated with RSA reactivity during the cold pressor (B = -0.003, SE = 0.005, z = -0.70, p = .48). After controlling for change in orbicularis oculi activation, smiling was not a significant predictor of RSA reactivity during the cold pressor (B = -0.0004, SE = 0.17, z = 0.00,

$p = 1.00$). The indirect effect coefficient was not significant ($B = 0.02$, SE = 0.04, $z = 0.67$, $p = .50$). Therefore, these results do not support the mediational hypothesis that change in orbicularis oculi activation would mediate the relationship between Duchenne smiling and RSA reactivity during the cold pressor.

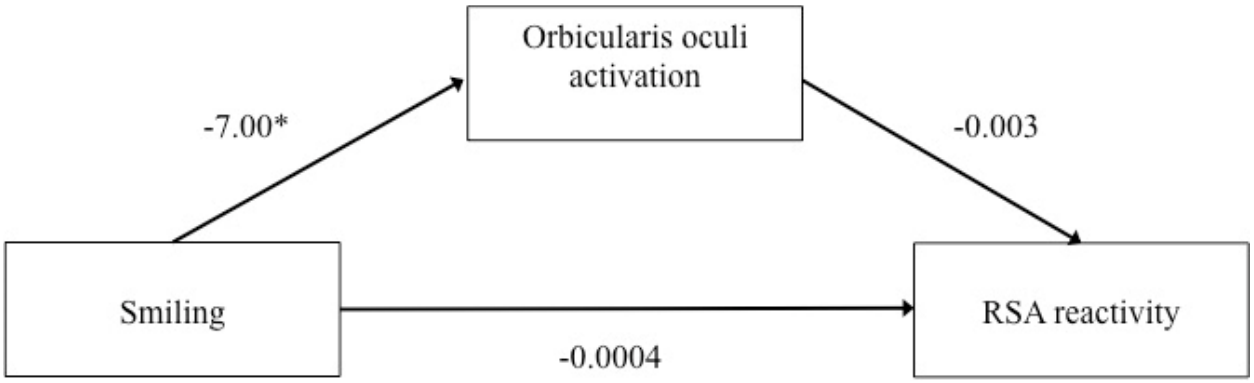

Figure 21. Unstandardized regression coefficients for the relationship between smiling and RSA reactivity during the cold pressor as mediated by change in orbicularis oculi activation.

* $p \leq .05$

RSA recovery. Orbicularis oculi activation significantly fully mediated the relationship between smiling during the pressure algometer task and RSA recovery. Smiling during the pressure algometer task was significantly associated with change in orbicularis oculi activation such that, on average, individuals who were randomly assigned to make Duchenne smiles had orbicularis oculi activation change scores that were 6.18 Hz higher than individuals who were randomly assigned to make neutral facial expressions ($B = -6.18$, SE = 0.72, $z = -8.53$, $p < .001$; Figure 22). Orbicularis oculi activation change scores were significantly associated with RSA recovery from the pressure algometer task such that for every one Hz increase in orbicularis oculi activation change, RSA recovery increased by .02 ($B = 0.02$, SE = 0.009, $z = 2.20$, $p = .03$). Thus, higher orbicularis oculi activation during the pressure algometer task was significantly

associated with higher RSA recovery. After controlling for change in orbicularis oculi activation, smiling was not a significant predictor of RSA recovery following the pressure algometer task (B = 0.14, SE = 0.10, z = 1.42, p = .16). The indirect effect coefficient was significant (B = -0.13, SE = 0.06, z = -2.13, p = .03), meaning that change in orbicularis oculi activation explained a significant amount of variation in the relationship between smiling and RSA recovery. Therefore, these results support the mediational hypothesis that change in orbicularis oculi activation would mediate the relationship between Duchenne smiling and RSA recovery following the pressure algometer task.

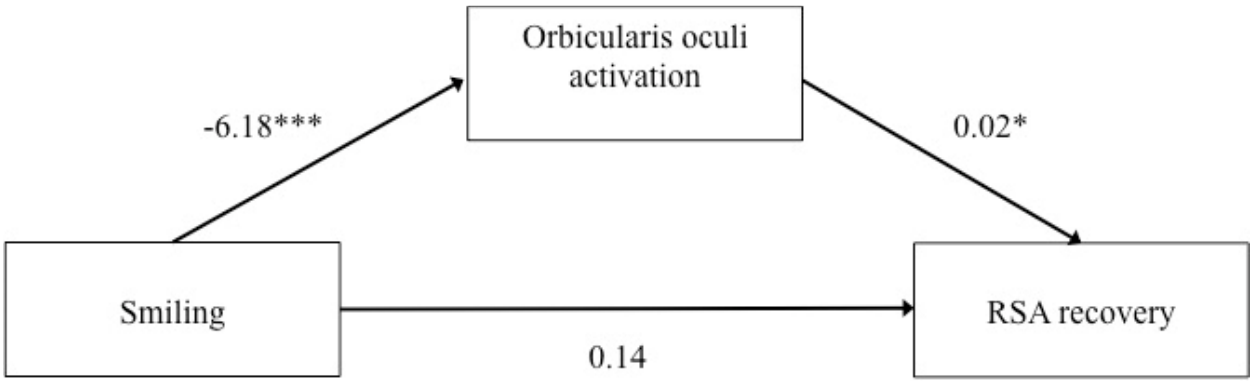

Figure 22. Unstandardized regression coefficients for the relationship between smiling and RSA recovery following the pressure algometer task as mediated by change in orbicularis oculi activation.

* $p \leq .05$, *** $p \leq .001$

Smiling during the cold pressor was significantly associated with change in orbicularis oculi activation such that, on average, individuals who were randomly assigned to make Duchenne smiles had orbicularis oculi activation change scores that were 7.05 Hz higher than individuals who were randomly assigned to make neutral facial expressions (B = -7.05, SE = 2.94, z = -2.40, p =.02; Figure 23). Orbicularis oculi activation change scores were not

significantly associated with RSA recovery following the cold pressor (B = -0.002, SE = 0.003, z = -0.87, p = .39). After controlling for change in orbicularis oculi activation, smiling was not a significant predictor of RSA recovery following the cold pressor (B = 0.006, SE = 0.10, z = 0.06, p = .95). The indirect effect coefficient was not significant (B = 0.02, SE = 0.02, z = 0.82, p = .41). Therefore, these results do not support the mediational hypothesis that change in orbicularis oculi activation would mediate the relationship between Duchenne smiling and RSA recovery following the cold pressor.

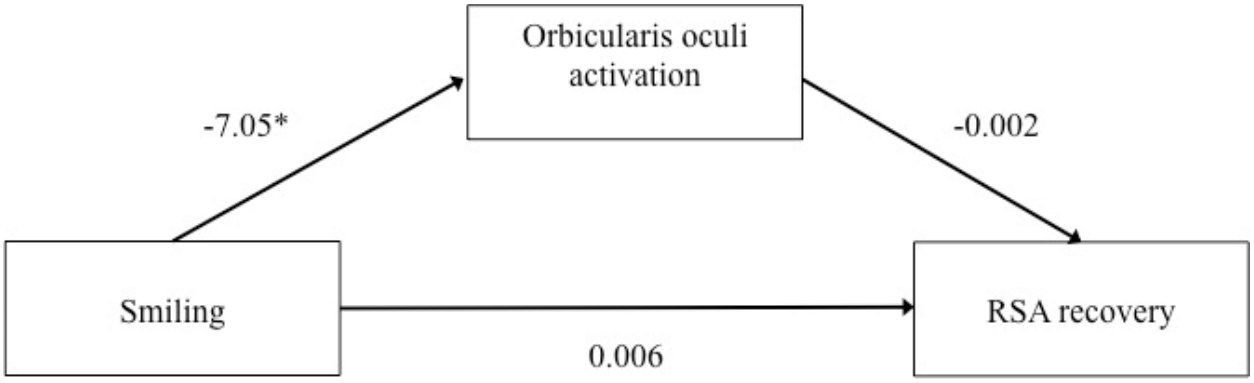

Figure 23. Unstandardized regression coefficients for the relationship between smiling and RSA recovery following the cold pressor as mediated by change in orbicularis oculi activation.

* $p \leq .05$

Discussion

This study demonstrated that Duchenne smiling did not buffer the cardiovascular effects of acute physical pain as compared to grimaces or neutral facial expressions. Furthermore, tolerance and self-reported pain during the two pain tasks did not differ based on facial expression condition. However, participants who were making Duchenne smiles during the cold pressor had higher pain threshold levels than participants who were making grimaces, although there were no differences between either of these groups and the neutral facial expression

condition. Pain threshold levels during the pressure algometer task were not different across conditions.

Why did participants who were Duchenne smiling during the cold pressor have higher pain threshold levels than participants making grimaces? Pain threshold was one of three self-reported outcome variables of interest (the other two were pain tolerance and self-reported pain), so it is somewhat surprising that these differences were not found across all three self-reported outcomes. However, pain threshold is a distinct outcome because it has to do with one's definition and perception of physical pain. One explanation is that participants who were making grimaces, which may be a more difficult facial expression to make than Duchenne smiles, wanted the task to be over more quickly and, therefore, reported earlier pain threshold times. However, participants were asked, "How difficult was it to hold the chopsticks like this?" after the cold pressor on a 0-100 scale, and these difficulty ratings did not significantly differ between the Duchenne smile condition (M = 42.45, SD = 29.12) and the grimace condition (M = 37.72, SD = 26.83), $t(151) = -1.04$, $p = .30$. Another possible explanation is that smiling may release endorphins, which can increase pain threshold. Although this specific hypothesis has not been tested, research has determined that laughter increases pain threshold (Dunbar et al., 2012), possibly through the release of endorphins, and there is ample evidence connecting endorphins to pain reduction (Basbaum & Fields, 1984; Mueller et al., 2010). This is the first study to determine that Duchenne smiling during pain may increase pain threshold times as compared to grimaces, but further research is needed in order to replicate this effect and investigate possible pathways that might contribute to this finding.

Mediation analyses provided some support for the role of PA as a mediator in the relationship between smiling and outcome variables of interest (HR, RSA, PEP, and self-

reported pain). Multiple mediation analyses demonstrated that participants who were randomly assigned to make Duchenne smiles during the pressure algometer task had less of a decrease in PA than participants who were randomly assigned to make neutral facial expressions, but this was not true during the cold pressor task. Thus, it seems that Duchenne smiling may have had a buffering effect on ratings of positivity during pressure pain as opposed to cold-induced pain. It may be the case that this buffering effect is only present during painful tasks in which the pain is steadily increasing (like the pressure algometer task). The cold pressor task, on the other hand, is immediately painful, but that pain levels off over time as the participant's hand begins to numb. This indicates the importance of considering different types of pain in the exploration of psychological-pain connections. Psychologists often use physical pain tasks interchangeably, but this study suggests that there may be important differences in the role of certain psychological factors across distinct types of pain. Therefore, future research should give careful thought to the choice of which experimental physical pain task to use and exercise caution in generalizing findings to other types of pain.

The outcome variable with which self-reported PA had the strongest mediational relationship was self-reported pain. PA fully mediated the relationship between smiling and self-reported pain during the pressure algometer task, although this mediation was only marginally significant. Individuals who were making Duchenne smiles during the pressure algometer task decreased in PA *less* than individuals who were making neutral facial expressions (this relationship also existed during the cold pressor task). Furthermore, individuals who reported higher PA during the pressure algometer task also reported less pain during the pressure algometer task. This mediation was in the expected direction, and these findings map well onto past research on the effects of PA inductions on pain (e.g., Bruehl, Carlson, & McCubbin, 1993).

Although no facial expression condition differences were found for self-reported pain in the main analyses, these differences could have been masked by the mediating role of PA. Thus, future research on smiling and self-reported pain should consider PA as an important mediator of this relationship.

Some of the most important set of findings from this study was that orbicularis oculi activation fully mediated the relationship between smiling and RSA recovery during the pressure algometer task. As expected, smiling was significantly associated with higher orbicularis oculi activation during the pressure algometer task as compared to neutral facial expressions. Orbicularis oculi activation was also significantly associated with RSA recovery during the pressure algometer task, such that higher orbicularis oculi activity during the task was connected with higher RSA recovery from the task. This is the only study to my knowledge that has provided support for the hypothesis that the oculocardiac reflex plays a role in the smiling to physiology connection. The activation of the orbicularis oculi muscles during Duchenne smiling may put pressure on other muscles around the eyes, which could activate the oculocardiac reflex. This reflex lowers pulse rate through stimulation of the vagus nerve (Lang et al., 1991). The vagus nerve is a central part of the parasympathetic nervous system, and activation of this system can be measured through RSA. Interestingly, orbicularis oculi activation change was not a significant mediator between smiling and RSA recovery from the cold pressor, or between smiling and RSA reactivity during either task. One possible explanation for these findings is that the lengths of time for which Duchenne smiles are held play a role. The average time that participants were engaged in the pressure algometer task was 145 seconds, whereas the average time that participants were engaged in the cold pressor task was 94 seconds. Therefore, it may take time for activation of the orbicularis oculi muscles to activate the oculocardiac reflex, which

is why the mediation only occurred for RSA recovery following the longer task, the pressure algometer. Future research should investigate this issue of timing, as well as determine whether activation of the orbicularis oculi muscles can, indeed, activate the oculocardiac reflex.

It should be noted that adherence to facial expression condition in this study was low. One hundred forty-four participants (62.07% of the sample) had facial expression adherence lower than five (on a ten point scale) during the pressure algometer task and 148 participants (63.79% of the sample) had facial expression adherence lower than five during the cold pressor. This means that almost two-thirds of the total sample held their assigned facial expressions for less than half of the time of each of the pain tasks. Furthermore, the majority of the participants who had facial expression adherence higher than five during the pressure algometer task were in the neutral facial expression condition (78 out of 84); only seven were in the grimace condition and three were in the Duchenne smile condition (sample sizes were similar for the cold pressor). Past studies (e.g., Soussignan, 2002) have removed participants from analyses who did not successfully engage in the facial expression manipulation, but these analyses were unfortunately not possible to run with such small remaining sample sizes of the Duchenne smile and grimace conditions. Future studies should take into account that both the Duchenne smile and grimace facial expression manipulations were difficult to hold for longer than one minute; adherence rapidly dropped after the first minute of the task. Analyses (not shown) were rerun using only the first minute of the cold pressor as the reactivity point for HR, RSA, and PEP (excluding minutes two, three, and four), since facial expression manipulations were strongest at this point; however, the pattern of results remained the same.

One of the concerns with participants stopping the painful tasks before the full four minutes were up was that there would be a large amount of missing data. Indeed, only 24.03% of

the participants lasted for all four minutes of the pressure algometer task, and only 24.89% of participants lasted for all four minutes of the cold pressor. More than half of these participants completed both of the pain tasks, which means that 35.19% of the total sample stayed in at least one pain task for four minutes. In order to determine that results were not affected by this abundance of missing data, results were reran with average HR, RSA, and PEP reactivity instead of reactivity across the four minutes of the tasks. The pattern of results remained the same. Furthermore, participants who completed at least one pain task were spread out equally across the three facial expression conditions, indicating that facial expression condition does not seem to explain why some participants lasted the full four minutes and why some participants did not.

As part of the study debriefing, participants were asked an open-ended question about what they thought the purpose of the chopsticks was. Analyses (not shown) were rerun excluding 12 participants who referenced specific facial expressions (grimace or smile) or emotions in their answers, but the pattern of results remained the same. Overall, it seemed that the majority of participants believed the cover story that this study was investigating multitasking, or they thought the chopsticks were supposed to serve as a distraction from the painful tasks.

There were a number of limitations to this study. One limitation was that it involved an extremely complicated protocol, with participants holding chopsticks in their mouths and reporting on their levels of positivity, negativity, and pain every 30 seconds during painful tasks, all while having EKG sensors on their cores and EMG sensors on their faces. Because this was such an involved protocol, it could have led to errors on the side of the research assistants and inaccurate self-reports (due to distraction) from the participants. Another limitation was that the sample was comprised solely of undergraduate students from UCI, so these results are not generalizable to other populations. In addition, missing data was a concern across a variety of

variables for a number of reasons. There was a moderate amount of missing PEP data due to technical issues in the middle of the study (11.58% of participants) and a moderate amount of missing pain threshold data because participants forgot to indicate when they first felt pain during the pressure algometer task (20.17% of participants) and cold pressor (16.74% of participants). Future studies that use these measures should take the possibility of lost/missing data into account when conducting initial power analyses. Finally, future research should investigate new methods and study designs that allow for improved adherence but not distraction from the tasks at hand. Reminders from research assistants to participants about their facial expression conditions are suboptimal since they may distract participants from the task at hand, but including a longer facial expression training period or placing more emphasis on the importance of holding the facial expression may help the issue of low facial expression adherence in future studies.

Study 2

Overview

The goal of this study was to determine whether experimentally manipulated smiling could buffer the negative psychological and physiological effects of social pain as induced through a social exclusion paradigm.

Hypotheses

I hypothesized that participants who were randomly assigned to make Duchenne smiles during the social pain task would have different cardiovascular trajectories (across HR, RSA, and PEP) than participants who were randomly assigned to make neutral facial expressions, driven by lower cardiovascular reactivity during the task and faster cardiovascular recovery after the task. I also hypothesized that participants who were randomly assigned to make Duchenne smiles

during the social pain task would self-report lower levels of pain immediately following the social pain task than participants who were randomly assigned to make neutral facial expressions. Finally, I hypothesized that PA would mediate the relationship between smiling and the four outcome variables of interest (HR, RSA, PEP, and self-reported pain).

Method

Participants. Participants were 350 undergraduate students at the University of California, Irvine, who completed the study for either course credit or pay (based on a power analysis with power set at 0.9 and effect size set at 0.25 [small to medium effect size]). Participants were excluded from the study if they had a psychological disorder (e.g., clinical depression, anxiety disorder, bipolar disorder) for which they were currently being treated (e.g., medication, therapy); had cardiovascular disease (e.g., a heart condition, hypertension); had a facial muscular disorder (e.g., Moebius syndrome, facioscapulohumeral muscular dystrophy); were not fluent in English (both reading and writing); took medication not approved by the study team that day (e.g., mood-altering medication); or had ingested caffeine in the two hours prior to the study (affects cardiovascular functioning). Sixteen participants (4.6% of the sample) did not complete the study due to technical issues. The final sample size was 334 participants (64.7% female, mean age = 20.63). Participants who completed the study for pay were compensated $5 for every 30 minutes completed of the study. The ethnicity breakdown of the participants was 40.4% Asian or Pacific Islander, 27.5% Hispanic or Latino, 14.1% White or Caucasian, 4.8% biracial, 1.8% Black or African-American, and 2.7% other.

Procedure. This study was approved by the Institutional Review Board at the University of California, Irvine. Upon arrival to the lab, participants were told that the researchers were waiting for two more participants to come to the lab, but that they could set the participant up

while they were waiting. Participants were told that the purpose of the study was to examine the psychological and physiological effects of multi-tasking during both social and non-social tasks. After participants were consented, they completed a screening questionnaire. If participants were not eligible for the study, they were thanked for their time and dismissed. If participants were eligible, they were randomly assigned to one of four conditions: Duchenne smile included during Cyberball (n=82), Duchenne smile excluded during Cyberball (n=85), neutral facial expression included during Cyberball (n=81), or neutral facial expression excluded during Cyberball (n=86).

The researchers measured participants' weight, height, waist, hip, and arm circumference. Participants were asked to remove all jewelry, and then the researchers connected them to an ECG. Five electrodes were placed on the participant's core and two electrodes were placed on their back in order to measure HRV and ICG. Electrode areas were cleaned with alcohol wipes before electrodes were applied to the skin. The participant was video recorded throughout the study in order to code for adherence to facial expression condition. The researchers then left the room while the participants completed baseline questionnaires. Upon completion of these questionnaires, participants sat quietly for six minutes so baseline physiological data could be obtained.

Participants engaged in three separate tasks during which continuous HRV and ICG were taken. Two of these tasks were non-social in nature and were used to distract the participant from the purpose of the study. The "social" task was Cyberball, the computer equivalent of "catch" over the Internet played with two other "participants" in the study. Before the task, participants were trained on their facial expression condition using the same protocol as in Study 1. Participants were told the task involved working on their mental visualization skills and had nothing to do with their performance in the game. They were asked to visualize the situation,

themselves, and the other players. This minor deception was necessary because participants may not have felt the negative effects of social exclusion if they knew they were going to be excluded beforehand.

In Cyberball, three "hands" were shown in a triangle, and one of them was controlled by the participant. Two hands were controlled by a computerized logarithm to either include or exclude the participant. A computer ball was thrown back and forth among the three hands. When the ball landed in the participants' hands, they could click on either the hand on the left or the hand on the right to throw the ball to one of the other "participants." Participants were told that they were playing against two other real participants via the Internet. In reality, the other two hands on the screen were controlled by the computer and operated according to parameters set by the experimenter. In the "included" condition, the participant received the ball a third of the time; in the "excluded" condition, the participant received the ball less than a third of the time. The computer hands were programmed to throw the ball after one second with a random amount of time between zero and two seconds added to each throw. The Cyberball game in both conditions lasted for three minutes. Upon completion of Cyberball, participants were told to sit still during a six-minute recovery period. They then completed a few brief questionnaires regarding their current mood and levels of pain.

Measures.

Physiological. The ECG and ICG set-ups were the same as described in Study 1.

Manipulation checks. Participants completed the Need-Threat Scale (Williams, Kippling, et al., 2000) after Cyberball to determine whether Cyberball resulted in quantifiable social distress. Example items from this scale are "I felt disconnected" and "I felt rejected." Participants were asked to indicate the extent to which they experienced these feelings during

Cyberball on a 1 (not at all) to 5 (very much so) scale. Participants were also asked to what extent they would agree with the statements regarding their experience with Cyberball "I was ignored" and "I was excluded" on the same scale.

Self-reported affect and pain. Please refer to Study 1 for information regarding the measurement of trait and state affect. The item "in pain" was added to the state affect questionnaire. State affect was measured twice throughout the study: once at baseline and once after Cyberball.

Covariates. Participants reported on their age, sex, ethnicity, and a number of health behaviors known to influence cardiovascular health, including smoking, drinking, exercising, and sleeping. Levels of perceived stress were measured by the Perceived Stress Scale (4-item; Cohen et al., 1983). Levels of depression were measured by the Center for Epidemiological Studies Depression Scale (10-item; Radloff, 1977). Levels of loneliness were measured by the short version of the UCLA Loneliness Scale (8-item; Russell, 1996).

Facial coding. The videos of participants holding the chopsticks in their mouths during Cyberball were coded with the same procedure as in Study 1. Cohen's kappa values ranged from .23 to .47, which have been suggested in recent literature to represent minimal to weak agreement among coders (McHugh, 2012). Average adherence to the Duchenne smile condition was 5.73 and to the neutral facial expression condition was 5.40 (out of 10).

Data analysis.

Main analyses. The main cardiovascular physiological response variables of interest were HR, RSA, and PEP. For cardiovascular reactivity and recovery analyses (looking at HR, RSA, and PEP separately), multi-level modeling was used to examine whether the trajectories differed across the four conditions. There were ten time intervals: average baseline, three one-

minute intervals during Cyberball (reactivity), and six one-minute intervals post task (recovery). The amount of variation that existed at each level was assessed using an unconditional means model with no predictors entered. An unconditional growth model was examined to determine whether within-person variation was systematically associated with time (maximum likelihood estimations indicated that quadratic time was the most appropriate to include for all cardiovascular outcome variables). A random intercept and random slope improved all model fits so were included on the random effects side of the models. The Duchenne excluded condition was chosen as the reference group for the main model because it was the condition of highest interest to study hypotheses. Pairwise contrasts were used to compare both the trajectories of cardiovascular variables of interest between all conditions and levels of the cardiovascular variables of interest at each time point between all conditions.

The main self-reported outcome variable of interest was pain. A change score for self-reported pain was calculated by subtracting self-reported pain before Cyberball from self-reported pain after Cyberball. Linear regressions were conducted to compare self-reported pain levels across the four conditions, which were dummy coded.

Covariates that were considered in analyses were age, sex, ethnicity, BMI, smoking status, drinking, exercise, sleep, trait affect, perceived stress, depression, loneliness, and adherence to facial expression condition. If any of these covariates were associated with the dependent variable of interest, they were controlled for within the analysis.

Mediation analyses. As in Study 1, seemingly unrelated regressions were used to determine whether PA mediated the relationship between smiling and the three main cardiovascular variables of interest (HR, RSA, and PEP) during reactivity and recovery. Seemingly unrelated regressions were also used to determine whether PA mediated the

relationship between smiling and self-reported pain. The independent variable was whether participants were making Duchenne smiles or neutral facial expressions while they were being excluded from Cyberball (the Duchenne excluded condition was the reference group); thus, mediation analyses were only conducted between the Duchenne excluded and neutral excluded conditions. PA change scores were calculated by subtracting baseline state PA from PA reported after Cyberball and were tested as the mediator in regression analyses. Reactivity and recovery change scores for cardiovascular variables of interest were calculated by subtracting average baseline levels from average reactivity and recovery levels.

Outliers. Outliers were treated the same as in Study 1.

Results

Manipulation check. Participants who were excluded during Cyberball felt significantly more excluded ($M = 4.02$, SD = 1.15) than participants who were included ($M = 1.62$, SD = 1.00), $t(331) = 20.22$, $p < .001$. Excluded participants also felt significantly more ignored ($M = 3.92$, SD = 1.17) than included participants ($M = 1.57$, SD = 0.89), $t(330) = 20.42$, $p < .001$, significantly more rejected ($M = 2.69$, SD = 1.35) than included participants ($M = 1.33$, SD = 0.68), $t(331) = 11.52$, $p < .001$, and significantly more disconnected ($M = 2.94$, SD = 1.35) than included participants ($M = 1.55$, SD = 0.95), $t(331) = 10.81$, $p < .001$.

HR. Eleven participants were outliers and were dropped from analyses. The means, standard deviations, and ranges of HR during baseline, reactivity, and recovery are reported in Table 12.

Table 12. Descriptive statistics for HR during baseline, reactivity, and recovery for each condition.

	Time								
	Baseline			Reactivity			Recovery		
Condition	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*
Duchenne excluded	71.25	8.65	50.50-93.25	70.18	8.64	51.00-92.28	73.15	8.60	53.42-94.04
Duchenne included	71.41	10.18	52.81-98.36	69.71	9.74	47.62-95.93	72.95	10.23	54.25-99.07
Neutral excluded	72.43	8.29	52.10-95.93	69.83	7.93	46.76-85.54	73.98	8.12	53.23-95.34
Neutral included	70.92	8.75	51.76-96.92	69.04	8.17	51.52-91.65	72.96	8.44	52.87-97.85

An unconditional means model showed that 87.78% of the variation in HR was due to between-person differences and 12.22% of the variation in HR was due to within-person differences. An unconditional linear growth model showed that there was significant between-person variation in change over time. The final model predicting HR responses to Cyberball included age and sex as covariates and the interaction between the quadratic form of time and facial expression condition. This interaction was significant ($\chi^2 = 14.39$, $p = .002$); therefore, the quadratic rate of change in HR was different across conditions (Table 13).

Table 13. Multilevel between-person effects of the interaction between facial expression condition and quadratic time on rate of change in HR.

Variable	Coefficients (RSE)	95% CI
Fixed Effects		
Intercept	77.42(2.82)***	[71.90, 82.95]
Sex[a]	1.61(1.13)	[-0.60, 3.83]
Age	-0.40(0.12)**	[-0.64, -0.16]
Time	0.64(0.12)***	[0.40, 0.87]
Condition		
Duchenne included	0.15(1.47)	[-2.88, 2,90]
Neutral excluded	0.66(1.35)	[-1.99, 3.30]
Neutral included	-0.86(1.36)	[-3.54, 1.81]
Condition[x]time		
Duchenne included	0.11(0.17)	[-0.23, 0.46]
Neutral excluded	-0.37(0.19)*	[-0.74, -0.08]
Neutral included	0.06(0.18)	[-0.30, 0.41]
Condition[x]time[x]time		
Duchenne included	-0.02(0.02)	[-0.06, 0.02]
Neutral excluded	0.05(0.02)**	[0.01, 0.09]
Neutral included	0.003(0.02)	[-0.04, 0.04]
Random Effects	Estimate (RSE)	95% CI
Random Part		
Random Intercept ($\hat{\sigma}_o^2$)	68.60(5.77)	[58.18, 80.90]
Random Slope ($\hat{\sigma}_1^2$)	0.08(0.02)	[0.05, 0.12]
Residual Variance	9.32(0.47)	[8.44, 10.29]

Note: Based on 294 participants with 2,938 longitudinal records. Duchenne excluded was the reference group for facial expression condition.
RSE = robust standard error
*$p \leq .05$
**$p \leq .01$
***$p \leq .001$
[a]Male was the reference group

In line with hypotheses, the Duchenne excluded and neutral excluded conditions had significantly different HR trajectories ($\gamma = 0.05$, $z = 2.64$, $p = .008$). The neutral excluded condition had a steeper trajectory during recovery than the Duchenne excluded condition (Figure 24). HR trajectories were also significantly different between the Duchenne included and neutral

excluded conditions (γ = 0.07, z = 3.69, p < .001) and between the neutral included and neutral excluded conditions (γ = 0.05, z = 2.40, p = .008). As with the Duchenne excluded condition, the Duchenne included and neutral included conditions have less steep trajectories during recovery than the neutral excluded condition. Multiple comparisons demonstrated that HR was not significantly different between any of the conditions at any of the ten time points.

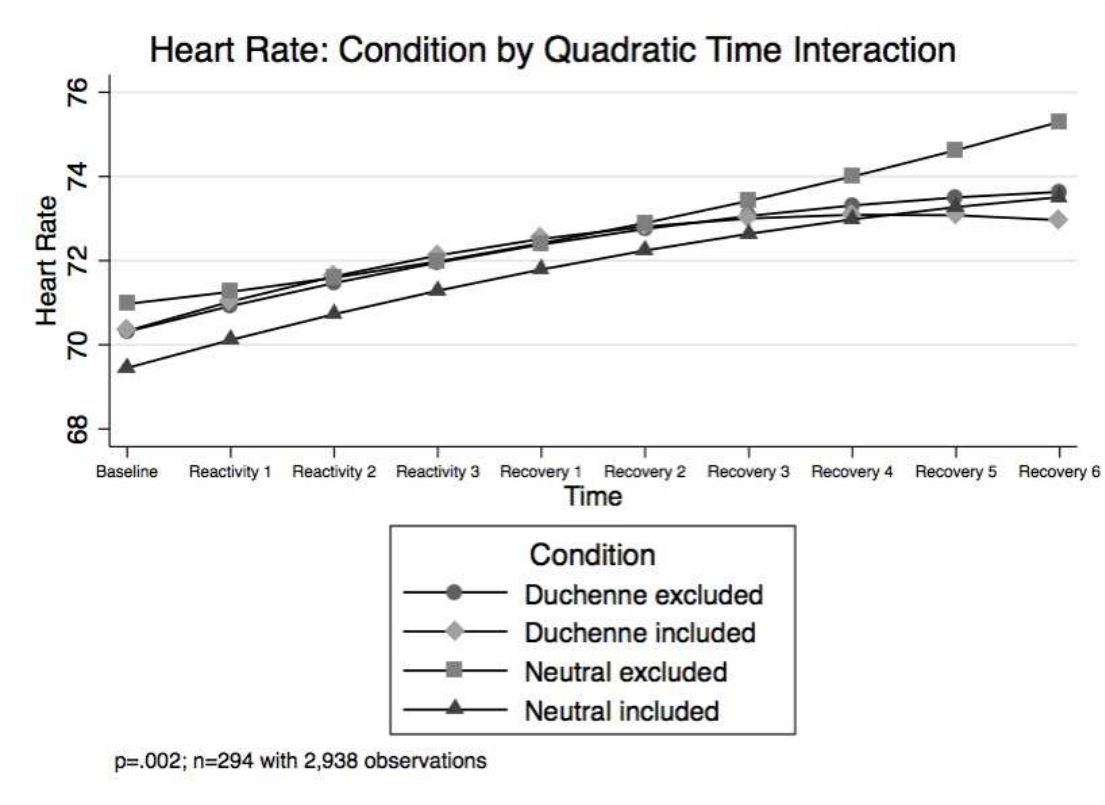

Figure 24. HR response to Cyberball by condition over time.

RSA. Thirteen participants were outliers and were dropped from analyses. The means, standard deviations, and ranges of RSA during baseline, reactivity, and recovery are reported in Table 14.

Table 14. Descriptive statistics for RSA during baseline, reactivity, and recovery for each condition.

	Time								
	Baseline			Reactivity			Recovery		
Condition	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*
Duchenne excluded	6.60	0.99	3.85-9.64	6.51	0.96	3.57-9.00	6.47	0.98	4.06-9.11
Duchenne included	6.45	0.96	4.15-8.66	6.42	0.88	4.42-8.21	6.41	0.94	4.25-8.49
Neutral excluded	6.41	1.01	3.92-9.24	6.33	1.03	3.72-8.64	6.16	0.95	4.05-9.24
Neutral included	6.69	0.97	4.46-8.79	6.55	1.02	3.52-9.26	6.41	0.91	4.00-8.88

A random quadratic slope improved the model fit so was included on the random side of the model. An unconditional means model showed that 75.49% of the variation in RSA was due to between-person differences and 24.51% of the variation in RSA was due to within-person differences. An unconditional linear growth model showed that there was significant between-person variation in change over time. No covariates significantly improved the model fit, so none were included in the final model. The final model predicting RSA responses to Cyberball included the interaction between the quadratic form of time and facial expression condition, which was not significant ($\chi^2 = 1.38$, $p = 0.71$). Therefore, the quadratic rate of change in RSA was not different across conditions (Table 15).

Table 15. Multilevel between-person effects of the interaction between facial expression condition and quadratic time on rate of change in RSA.

Variable	Coefficients (RSE)	95% CI
Fixed Effects		
Intercept	6.55(0.11)***	[6.34, 6.75]
Time	0.002(0.02)	[-0.04, 0.04]
Condition		
Duchenne included	-0.09(0.15)	[-0.38, 0.20]
Neutral excluded	-0.13(0.15)	[-0.43, 0.17]
Neutral included	0.14(0.16)	[-0.16, 0.45]
Condition^{x}time		
Duchenne included	-0.02(0.03)	[-0.08, 0.03]
Neutral excluded	-0.04(0.03)	[-0.10, 0.01]
Neutral included	-0.05(0.03)	[-0.11, 0.002]
Condition^{x}time^{x}time		
Duchenne included	0.004(0.003)	[-0.003, 0.01]
Neutral excluded	0.002(0.003)	[-0.004, 0.008]
Neutral included	0.003(0.003)	[-0.003, 0.009]
Random Effects	Estimate (RSE)	95% CI
Random Part		
Random Intercept ($\hat{\sigma}_o^2$)	0.80(0.07)	[0.67, 0.94]
Random Slope ($\hat{\sigma}_1^2$)	$8.27^{x}10^{-15}$ ($8.86^{x}10^{-14}$)	[$6.36^{x}10^{-24}$, $1.08^{x}10^{-5}$]
Random Quadratic Slope ($\hat{\sigma}_2^2$)	$1.87^{x}10^{-5}$ ($4.06^{x}10^{-6}$)	[$1.22^{x}10^{-5}$, $2.86^{x}10^{-5}$]
Residual Variance	0.26(0.01)	[0.24, 0.28]

Note: Based on 321 participants with 3,207 longitudinal records. Duchenne excluded was the reference group for facial expression condition.
RSE = robust standard error
***$p \leq .001$

Contrary to hypotheses, RSA trajectories were not significantly different between the Duchenne excluded and neutral excluded conditions ($\gamma = 0.002$, $z = 0.68$, $p = .49$). RSA trajectories were also not significantly different between any of the other four conditions (Figure 25). Multiple comparisons demonstrated that RSA was not significantly different between any of the conditions at any of the ten time points.

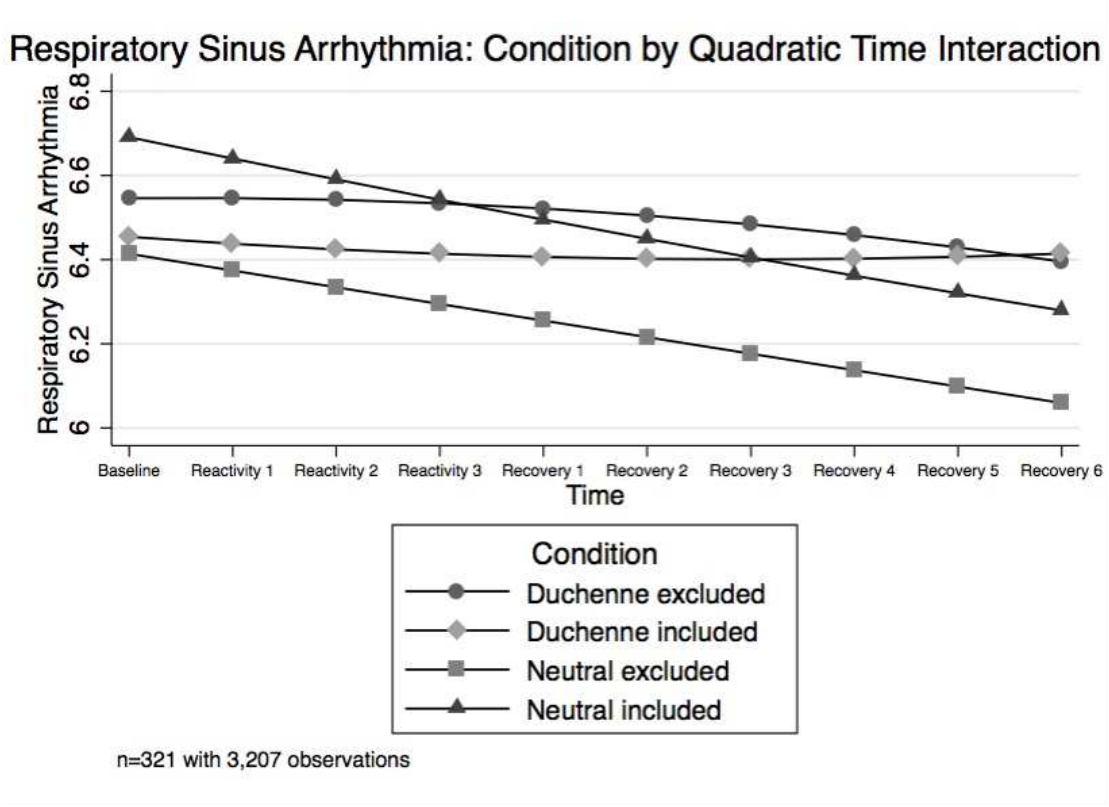

Figure 25. RSA response to Cyberball by condition over time.

PEP. Twenty-three participants were outliers and were dropped from analyses. The means, standard deviations, and ranges of PEP during baseline, reactivity, and recovery are reported in Table 16.

Table 16. Descriptive statistics for PEP during baseline, reactivity, and recovery for each condition.

	Time								
	Baseline			Reactivity			Recovery		
Condition	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*
Duchenne excluded	110.23	6.77	87.67-121.17	111.01	5.88	94.67-122.00	110.53	7.27	83.67-121.67
Duchenne included	111.22	6.48	97.67-131.00	111.12	6.31	83.00-120.33	112.10	6.10	96.33-126.50
Neutral excluded	111.50	6.86	90.00-122.00	111.00	7.47	84.33-122.00	111.25	7.02	84.33-122.00
Neutral included	109.23	8.05	73.17-121.50	109.68	7.17	74.67-121.00	109.96	6.77	80.50-120.33

An unconditional means model showed that 80.37% of the variation in PEP was due to between-person differences and 19.63% of the variation in PEP was due to within-person differences. An unconditional linear growth model showed that there was significant between-person variation in change over time. The final model predicting PEP responses to Cyberball included BMI as a covariate and the interaction between the quadratic form of time and facial expression condition, which was not significant ($\chi^2 = 2.28$, $p = .52$). Therefore, the quadratic rate of change in PEP was not different across conditions (Table 17).

Table 17. Multilevel between-person effects of the interaction between facial expression condition and quadratic time on rate of change in PEP.

Variable	Coefficients (RSE)	95% CI
Fixed Effects		
Intercept	115.87(1.68)***	[112.57, 119.17]
BMI	-0.23(0.07)**	[-0.38, -0.09]
Time	0.05(0.11)	[-0.17, 0.26]
Condition		
Duchenne included	0.71(1.00)	[-1.25, 2.66]
Neutral excluded	0.64(1.09)	[-1.50, 2.78]
Neutral included	-1.05(1.08)	[-3.16, 1.06]
Condition^{x}time		
Duchenne included	0.02(0.20)	[-0.37, 0.41]
Neutral excluded	-0.02(0.18)	[-0.37, 0.34]
Neutral included	0.15(0.16)	[-0.16, 0.47]
Condition^{x}time^{x}time		
Duchenne included	0.02(0.02)	[-0.02, 0.06]
Neutral excluded	0.007(0.02)	[-0.03, 0.05]
Neutral included	-0.01(0.02)	[-0.05, 0.03]
Random Effects	Estimate (RSE)	95% CI
Random Part		
Random Intercept ($\hat{\sigma}_o^2$)	39.57(2.76)	[31.39, 49.88]
Random Slope ($\hat{\sigma}_1^2$)	0.07(0.05)	[0.01, 0.30]
Residual Variance	10.07(2.76)	[5.88, 17.24]

Note: Based on 311 participants with 3,106 longitudinal records. Duchenne excluded was the reference group for facial expression condition.
RSE = robust standard error
**$p \leq .01$
***$p \leq .001$

Contrary to hypotheses, PEP trajectories were not significantly different between the Duchenne excluded and neutral excluded conditions ($\gamma = 0.007$, $z = 0.34$, $p = .73$). PEP trajectories were also not significantly different between any of the other four conditions (Figure 26). Multiple comparisons confirmed that PEP was not significantly different between any of the conditions at any of the ten time points.

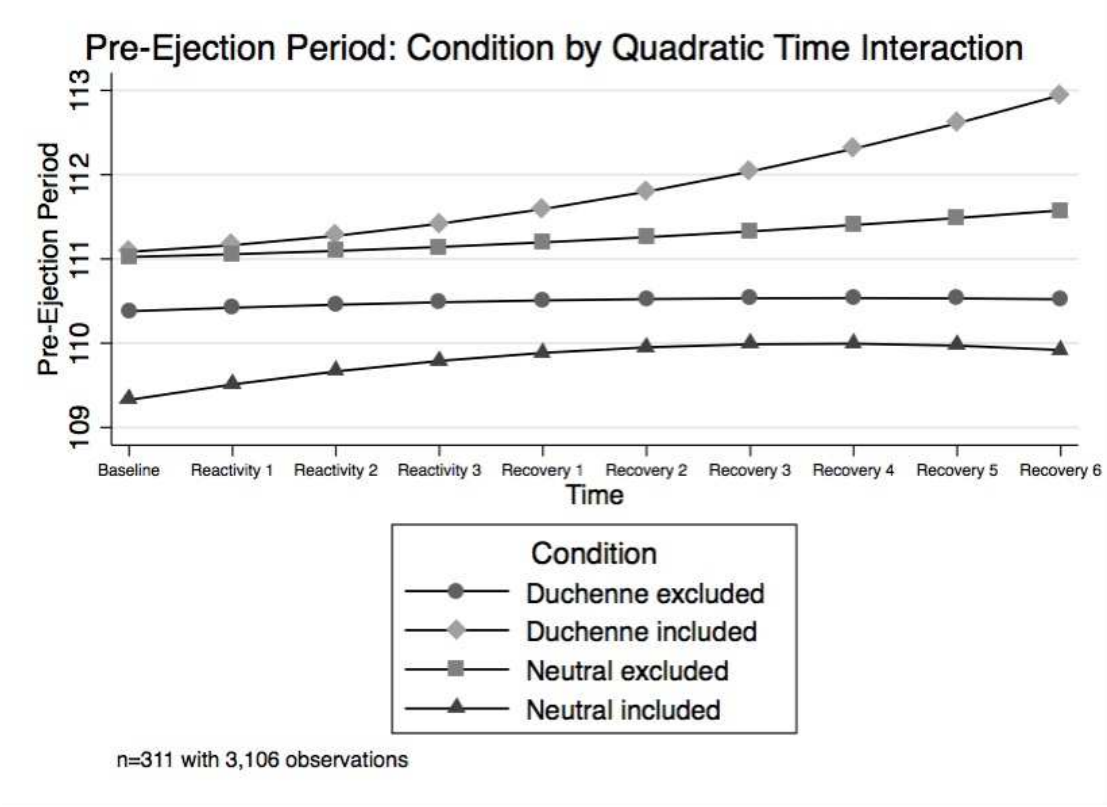

Figure 26. PEP response to Cyberball by condition over time.

Self-reported pain. Eleven participants were outliers and were dropped from analyses. No covariates were significantly associated with self-reported pain change scores, so none were included in linear regression analyses. Contrary to hypotheses, self-reported pain change scores were not significantly different between the Duchenne excluded and neutral excluded conditions (B = -0.02, SE = 0.07, t = -0.23, p = .82). Self-reported pain change scores were also not significantly different between the Duchenne excluded and Duchenne included conditions (B = 0.02, SE = 0.08, t = 0.31, p = .76); the Duchenne excluded and neutral included conditions (B = -0.07, SE = 0.07, t = -1.00, p = .32); the Duchenne included and neutral included conditions (B = -0.09, SE = 0.08, t = -1.21, p = .23); the Duchenne included and neutral excluded conditions (B =

-0.04, SE = 0.08, t = -0.52, p = .61); or the neutral excluded and neutral included conditions (B = -0.05, SE = 0.07, t = -0.76, p = .45).

Mediation analyses. As described in the Data Analysis section, seemingly unrelated regressions were conducted to determine whether PA mediated the relationship between smiling and cardiovascular outcome variables of interest (HR, RSA, and PEP) during reactivity and recovery. Seemingly unrelated regressions were also conducted to determine whether PA mediated the relationship between smiling and self-reported pain. Below, I test the path from the independent variable to the mediator; the path from the mediator to the dependent variable; and the path from the independent variable to the dependent variable, controlling for the mediator. I also test the overall indirect effect coefficient to determine whether each mediational hypothesis is supported.

Average change in state PA was -.22 for the Duchenne excluded condition; -.19 for the Duchenne included condition; -.20 for the neutral excluded condition; and -.17 for the neutral included condition. These changes in state PA were not significantly different among conditions, F(3, 289) = 0.11, p = .95. The same outliers from main analyses were excluded from mediation analyses.

HR. Smiling during Cyberball was not significantly associated with PA change scores (B = 0.05, SE = 0.09, z = 0.53, p = .60). Higher PA change scores were not significantly associated with HR reactivity during Cyberball (B = 0.11, SE = 0.47, z = 0.23, p = .82) or HR recovery following Cyberball (B = 0.16, SE = 0.38, z = 0.41, p = .68). After controlling for change in PA, as compared to those in the neutral excluded condition, those who were in the Duchenne excluded condition had significantly higher HR reactivity, which was contrary to hypotheses (B = -1.64, SE = 0.53, z = -3.09, p = .002; Figure 27), but not HR recovery (B = -0.39, SE = 0.44, z

= -0.90, p = .37). The indirect effect coefficient was not significant for the HR reactivity mediation analysis (B = 0.01, SE = 0.02, z = 0.21, p = .84) or the HR recovery mediation analysis (B = 0.01, SE = 0.02, z = 0.32, p = .75). Therefore, neither of these results supports the mediational hypotheses.

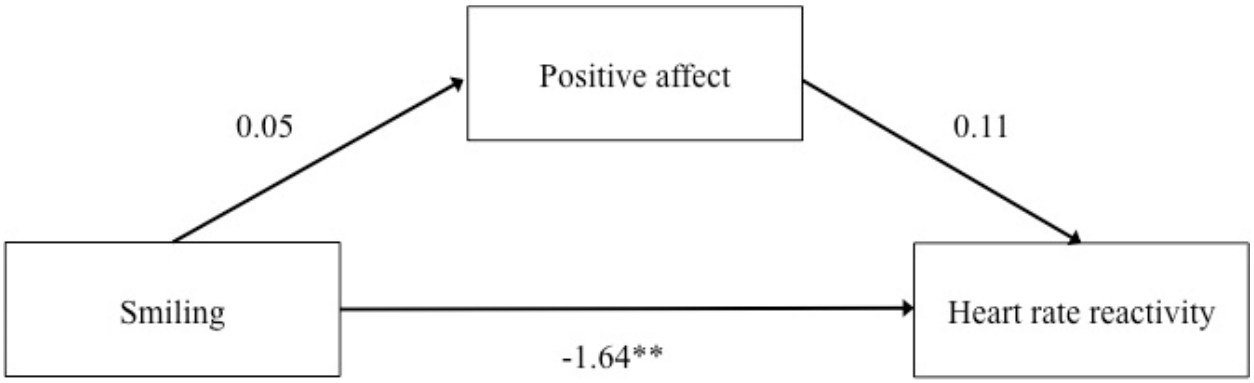

Figure 27. Unstandardized regression coefficients for the relationship between smiling and HR reactivity as mediated by change in PA.

**$p \leq .01$

RSA. Smiling during Cyberball was not significantly connected with PA change scores (B = 0.05, SE = 0.09, z = 0.59, p = .55). PA change scores were not significantly associated with RSA reactivity during Cyberball (B = -0.002, SE = 0.08, z = -0.03, p = .98) or RSA recovery following Cyberball (B = -0.02, SE = 0.06, z = -0.27, p = .79). After controlling for change in PA, smiling during Cyberball was not a significant predictor of RSA reactivity (B = -0.008, SE = 0.09, z = -0.09, p = .93) or RSA recovery (B = -0.11, SE = 0.07, z = -1.57, p = .12). The indirect effect coefficient was not significant for the RSA reactivity mediation analysis (B = -0.0001, SE = 0.004, z = -0.03, p = .98) or the RSA recovery mediation analysis (B = -0.0009, SE = 0.004, z = -0.24, p = .81). Therefore, neither of these results supports the mediational hypotheses.

PEP. Smiling during Cyberball was not significantly connected with PA change scores (B = 0.02, SE = 0.09, z = 0.20, p = .84). PA change scores were not significantly associated with PEP reactivity during Cyberball (B = 0.25, SE = 0.44, z = 0.58, p = .57) or PEP recovery following Cyberball (B = 0.30, SE = 0.31, z = 0.95, p = .34). Contrary to hypotheses, smiling during Cyberball was a significant predictor of higher PEP reactivity after controlling for change in PA (B = -0.91, SE = 0.48, z = -1.87, p = .06), although this was only marginally significant. Smiling during Cyberball was not significantly associated with PEP recovery after controlling for change in PA (B = -0.39, SE = 0.35, z = -1.11, p = .27). The indirect effect coefficient was not significant for the PEP reactivity mediation analysis (B = 0.004, SE = 0.02, z = 0.19, p = .85) or the PEP recovery mediation analysis (B = 0.005, SE = 0.03, z = 0.19, p = .85). Therefore, neither of these results supports the mediational hypotheses.

Self-reported pain. Smiling during Cyberball was not significantly connected with PA change scores (B = 0.04, SE = 0.10, z = 0.38, p = .71). PA change scores were not significantly associated with self-reported pain change scores (B = -0.07, SE = 0.06, z = -1.22, p = .22). After controlling for change in PA, smiling during Cyberball was not a significant predictor of self-reported pain change scores (B = -0.01, SE = 0.07, z = -0.19, p = .85). The indirect effect coefficient was not significant (B = -0.003, SE = 0.008, z = -0.36, p = .72). Therefore, these results do not support the mediational hypothesis.

Discussion

Participants who made Duchenne smiles during social pain had significantly different HR trajectories than participants who made neutral facial expressions, but RSA and PEP trajectories did not significantly differ among facial expression conditions. Furthermore, smiling during

social pain did not have an effect on self-reported pain. In mediation analyses, PA did not mediate the relationship between smiling and HR, RSA, PEP, or self-reported pain.

The HR findings in this study align with past literature on the cardiovascular benefits of Duchenne smiling during acute pain (Kraft & Pressman, 2012; Pressman et al., under review). These past studies have found that smiling during physical pain is most beneficial during the cardiovascular recovery period, which was the same for this study. However, it is important to note that although Cyberball has been used in past studies as a social exclusion stressor that elicits normal cardiovascular stress responses (e.g., Iffland et al., 2014; Williamson, Thomas, Eisenberger, & Stanton, 2018), participants in this study did not display normal HR stress responses. HR, which should increase during reactivity and decrease during recovery, did the opposite; it *decreased* during reactivity and *increased* during recovery across all four conditions. Average HR during Cyberball for participants who were excluded was 70.67 beats per minute (bpm), 1.84 bpm *lower* than the average baseline HR of 72.51 bpm. However, participants who were excluded during Cyberball reported higher levels of exclusion, rejection, isolation, and feeling disconnected after playing Cyberball than those who were included during the game, levels comparable to those of past studies (e.g., Williamson et al., 2018). Thus, it seems that Cyberball was psychologically but not physiologically stressful for participants. It may be the case that as video games are rapidly evolving and becoming more life-like, the simple graphics of Cyberball are less convincing and feel less real, especially to younger populations. One possible future direction for work in this area is to create a more believable virtual social exclusion paradigm, such as an online chat room. Furthermore, validated in-person social exclusion paradigms such as the YIPS (Stroud et al., 2000) may be more powerful than online paradigms and should be investigated within future research in this area.

As in Study 1, adherence to facial expression condition in this study was low. One hundred forty-two participants (42.51% of the sample) had facial expression adherence lower than five (on a ten point scale), which means they held their assigned facial expression for less than half of the three minute Cyberball game. Analyses were rerun excluding these participants (97 in one of the two Duchenne smile conditions and 95 in one of the two neutral facial expression conditions), but the pattern of findings remained the same, suggesting that low adherence to facial expression condition was not a driving force of the results. However, future studies should take into account that both the Duchenne smile and neutral facial expression manipulations were difficult to hold for three minutes; adherence rapidly dropped after the first minute of the task. Analyses were rerun using only the first minute of Cyberball as the reactivity point (excluding minutes two and three), since facial expression manipulations were strongest at this point. The pattern of results remained the same for RSA and PEP, but the interaction between condition and quadratic time for HR analyses was no longer significant, meaning that there were no longer significant differences between conditions. This is not surprising, however, since participants had not yet been excluded from Cyberball, which happened after the one-minute mark. Thus, stressful tasks that only last for one minute may be more appropriate contexts in which to research the effects of facial expressions on cardiovascular outcomes.

Following participant 27, I added a number of debriefing questions to the study to determine whether participants were fooled by the Cyberball manipulation. Fifteen participants said that they were familiar with the Cyberball manipulation and 40 participants responded with "0" to the question, "How many people were playing the virtual ball-throwing game with you?" This moderate rate of detection (16.5% of participants) is most likely due to the fact that the Cyberball manipulation was taught in a Social Psychology class in the department when this

study was being conducted. Analyses were rerun excluding these 55 people but the pattern of results remained the same. Furthermore, excluding these participants did not change overall cardiovascular reactivity to Cyberball. Participants were also asked, "Have you seen this chopstick manipulation before?" Only two participants answered yes to this question and excluding them from analyses did not change the pattern of results.

There were a number of limitations to this study. One limitation was that, as in Study 1, the sample was comprised solely of undergraduate students from UCI, so these results are not generalizable to other populations. Another limitation, as mentioned above, was that PA, NA, and self-reported pain were only measured two times during the study: at baseline and post Cyberball. These limited measurements could have missed subtle affective changes over the course of the stressor. Furthermore, this study did not include the measures used in Study 1 that asked about the participants' experiences with holding the chopsticks (how difficult/comfortable the task was, how tired their facial muscles were). Therefore, there is no indication of the distraction component of holding Duchenne smiles, which activate more facial muscles than neutral facial expressions. Finally, there were a number of technical difficulties with the Cyberball game that occurred over the course of the study, removing 16 participants from the study.

General Discussion

Taken together, these two studies provide only little support that Duchenne smiling can buffer the negative cardiovascular effects of physical and social pain. In Study 1, no cardiovascular differences between Duchenne smiles, grimaces, and neutral facial expressions were found during either physical pain task (the pressure algometer task or the cold pressor). In Study 2, participants who were randomly assigned to make Duchenne smiles during social pain

had significantly different HR trajectories than participants who were randomly assigned to make neutral facial expressions, but there were no differences in RSA or PEP trajectories. There were no significant differences in pain tolerance (Study 1) or self-reported pain (Study 1 or 2). However, pain threshold during the cold pressor in Study 1 was significantly higher for participants who made Duchenne smiles compared with participants who made grimaces. Some evidence was found in Study 1 to support both PA and orbicularis oculi activation as possible mediators between Duchenne smiling and outcome variables of interest during physical pain, but no support was found for PA as a mediator of this relationship during social pain (Study 2).

Overall, mediation analyses from Study 1 found mixed evidence for PA as a mediator between Duchenne smiling and outcome variables of interest. Multiple mediation analyses demonstrated that participants who were randomly assigned to make Duchenne smiles during the pressure algometer task had less of a decrease in PA than participants who were randomly assigned to make neutral facial expressions, but this was not true during the cold pressor task. Furthermore, PA fully (albeit marginally) significantly mediated the relationship between Duchenne smiling and self-reported pain during the pressure algometer task. One explanation for why PA effects were not found throughout all mediation analyses is that there was a camera present. Recent research has found that the presence of cameras during facial feedback experiments can dampen or even eliminate facial feedback effects, possibly because feeling observed reduces judgments that are made on internal cues (Noah et al., 2018). Unfortunately, the presence of a camera was necessary in both studies in order to code for facial expression adherence. Ethics board approval often requires that participants be informed that they will be videotaped during studies, but future studies should consider making the camera less visible to participants in the hopes that they will forget they are being videotaped during the study.

An additional explanation for the mixed facial feedback findings has to do with the length of time for which participants held the facial expressions. Ekman (1984) has suggested that emotional expressions generally last between 0.5 and four seconds. However, participants in Study 1 held the expressions for an average of 145 seconds during the pressure algometer task and 94 seconds during the cold pressor task, and participants in Study 2 held the facial expressions for three minutes during Cyberball. Past work on facial feedback has suggested that holding facial expressions for unnaturally long periods of time could create feedback that is discounted by the participant such that they do not report emotional effects (Matsumoto, 1987). Furthermore, the monotonicity theory of facial feedback posits that the strength of the facial expression positively correlates with the strength of emotional effects (Hess, Kappas, McHugo, Lanzetta, & Kleck, 1992), and the longer participants hold manipulated facial expressions, the weaker the expressions get. Therefore, future work in this area might want to consider manipulating facial expressions for shorter periods of time or doing brief but repeated holds that more closely approximate natural expressions. This, of course, would require the development of clever new cover stories that could obscure the purpose of the study.

Adherence to facial expression was a serious concern in both studies of this dissertation. One possible future solution for this issue is to give participants clearer and more transparent instructions about their facial expression manipulations. The issue of awareness, or whether or not participants know they are making a certain facial expression, affecting facial feedback effects is a notable debate within the facial feedback literature. Due to this concern, cover stories about multi-tasking were used in the two studies of this dissertation to minimize participants' awareness of facial expression manipulations. However, a recent meta-analysis of facial feedback effects found no differences across studies in which participants were aware vs. not

aware of the facial expression they were making (Coles et al., 2019). Therefore, future studies should consider dropping the cover story approach and, instead, informing participants of the facial expressions they will be making. This may lead to higher facial expression adherence; instead of being told to activate specific muscles, instructions with which participants sometimes struggle, participants could be told to create specific facial expressions, instructions that may be more comfortable and easily understood.

Although EMG data for both zygomaticus major and orbicularis oculi muscles were available for Study 1, it is not possible to use these data as a hard cutoff for whether or not a facial expression was strong enough or accurate. To the best of my knowledge, past research has not investigated the level of muscle activation for different muscles needed in order to create a facial expression. For example, in order to accurately create a Duchenne smile, how activated do the zygomaticus major and orbicularis oculi muscles need to be? Because these cutoffs do not exist, we used trained coders to code for facial expression condition adherence. However, it should be noted that agreement between coders was fairly low for both studies, most likely because activation of orbicularis oculi muscles is difficult to code. Some individuals show activation of this muscle group under their eyes, whereas others show activation around their eyes (creating "crow's feet"). Therefore, this low agreement among coders indicates the need for more in-depth facial coding training in future work. An important future direction would be to use coders trained in the Facial Action Coding System (FACS) to code specific action units in the face. Furthermore, a number of companies are developing facial coding software (such as Noldus FaceReader) that might be able to detect minute changes difficult to see with the human eye. This would allow an investigation into whether stronger activation of specific action units

(as opposed to overall adherence) plays a part in the relationship between smiling during pain and physiological/self-report outcome variables of interest.

What does it mean to take smiling out of its normal social context? Duchenne smiles serve a number of different social functions, including reinforcing specific social behaviors of individuals who view them (e.g., Shore & Heerey, 2011) and inducing trust (Centorrino, Djemai, Hopfensitz, Milinski, & Seabright, 2015). Furthermore, a recent meta-analysis determined that individuals who produce Duchenne smiles are seen as more genuine, trustworthy, attractive, real, and authentic than participants who produce non-Duchenne smiles (Gunnery & Ruben, 2016). However, if the only functions of smiles were of a social nature, we would never smile when are alone. This dissertation supports the idea that taking smiling out of a social context and merely activating the muscles associated with Duchenne smiles may be connected with important psychological and physiological outcomes.

There are a number of exciting future directions for research on smiling and health-relevant responses to take. First, future research should investigate the psychological and physiological effects of smiling in the context of real world stressful circumstances, such as undergoing a short, painful procedure at a doctor's office. Future research should also continue to investigate the possible activation of the oculocardiac reflex through Duchenne smiling, including how long smiles would need to be held in order to activate the reflex, through neuroscience studies. In addition, studies should investigate stressors of different lengths to see if there is a certain length of stressor for which smiling is most beneficial. Finally, future work should consider the best way to measure PA continuously across stressful tasks. It may be the case that asking participants to report their affect levels with a dial is less intrusive, which may lead to more accurate reports of PA.

This dissertation provides some evidence that Duchenne smiling during certain types of pain may affect both the psychology and physiology of the pain experience. Research in this area should continue to investigate a number of variables that may affect the relationship between smiling and health-relevant responses, including the presence of video cameras, length of time for which facial expressions are held, and adherence to facial expression condition. It is important to determine the specific situations in which smiling may be beneficial for pain before researchers consider designing interventions in this area, an important future direction for research in this area to take. If something as simple as a smile can buffer pain, then each and every person is already equipped with an effective strategy for combating the undesirable consequences of painful experiences.

References

Appelhans, B. M., & Luecken, L. J. (2008). Heart rate variability and pain: Associations of two interrelated homeostatic processes. *Biological Psychology*, *77*(2), 174–182. http://doi.org/10.1016/j.biopsycho.2007.10.004

Barak, E., & Weisenberg, M. (1988). Anxiety and attitudes toward pain as a function of ethnic grouping and socioeconomic status. *The Clinical Journal of Pain*, *3*, 189–196.

Basbaum, A. I., & Fields, H. L. (1984). Endogenous pain control systems: Brainstem spinal pathways and endorphin circuitry. *Annual Review of Neuroscience*, *7*, 309–338. http://doi.org/10.1146/annurev.neuro.7.1.309

Boiten, F. (1996). Autonomic response patterns during voluntary facial action. *Psychophysiology*, *33*, 123–131.

Breivik, H., Borchgrevink, P. C., Allen, S. M., Rosseland, L. A., Romundstad, L., Breivik Hals, E. K., … Stubhaug, A. (2008). Assessment of pain. *British Journal of Anaesthesia*, *101*(1), 17–24. http://doi.org/10.1093/bja/aen103

Bruehl, S., Carlson, C. R., & McCubbin, J. A. (1993). Two brief interventions for acute pain. *Pain*, *54*(1), 29–36.

Campbell, C. M., Edwards, R. R., & Fillingim, R. B. (2005). Ethnic differences in responses to multiple experimental pain stimuli. *Pain*, *113*, 20–26. http://doi.org/10.1016/j.pain.2004.08.013

Centorrino, S., Djemai, E., Hopfensitz, A., Milinski, M., & Seabright, P. (2015). Honest signaling in trust interactions: Smiles rated as genuine induce trust and signal higher earning opportunities. *Evolution and Human Behavior*, *36*(1), 8–16. http://doi.org/10.1016/j.evolhumbehav.2014.08.001

Chapman, R. C., Tuckett, R. P., & Song, C. W. (2008). Pain and stress in a systems perspective: Reciprocal neural, endocrine and immune interactions. *Journal of Pain*, *9*(2), 122–145. http://doi.org/10.1038/jid.2014.371

Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *Journal of Health and Social Behavior*, *24*(4), 385–396.

Coles, N. A., Larsen, J. T., & Lench, H. C. (2019). A meta-analysis of the facial feedback literature: Effects of facial feedback on emotional experience are small and variable. *Psychological Bulletin*. Advance online publication. http://doi.org/10.1037/bul0000194

Darwin, C. (1965). *The expression of the emotions in man and animals.* Chicago: University of Chicago Press. (Original work published 1872).

Davidson, K. W., Mostofsky, E., & Whang, W. (2010). Don't worry, be happy: Positive affect and reduced 10-year incident coronary heart disease: The Canadian Nova Scotia Health Survey. *European Heart Journal*, *31*(9), 1065–1070. http://doi.org/10.1093/eurheartj/ehp603

Davidson, R. J., Schwartz, G. E., Saron, C., Bennett, J., & Goleman, D. J. (1979). Frontal versus parietal EEG asymmetry during positive and negative affect. *Psychophysiology, 16*(2), 202-203.

Denver, J. W., Reed, S. F., & Porges, S. W. (2007). Methodological issues in the quantification of respiratory sinus arrhythmia. *Biological Psychology*, *74*(2), 286–294. http://doi.org/10.1016/j.biopsycho.2005.09.005

Dewall, C. N., Macdonald, G., Webster, G. D., Masten, C. L., Baumeister, R. F., Powell, C., … Eisenberger, N. I. (2010). Acetaminophen reduces social pain: Behavioral and neural evidence. *Psychological Science*, *21*(7), 931–937.

http://doi.org/10.1177/0956797610374741

Duchenne, G. B. (1990). *The mechanism of human facial expression.* (R. A. Cuthbertson, Ed. And Trans.). Cambridge: Cambridge University Press. (Original work published 1862).

Dunbar, R. I. M., Baron, R., Frangou, A., Pearce, E., van Leeuwen, E. J. C., Stow, J., … van Vugt, M. (2012). Social laughter is correlated with an elevated pain threshold. *Proceedings of the Royal Society B: Biological Sciences*, *279*(1731), 1161–1167. http://doi.org/10.1098/rspb.2011.1373

Eisenberger, N. I., Lieberman, M. D., & Williams, K. D. (2003). Does rejection hurt? An fMRI study of social exclusion. *Science*, *302*, 290–292. http://doi.org/10.1126/science.1089134

Ekman, P. (1984). Expression and the nature of emotion. In K. Scherer & P. Ekman (Eds.), Approaches to emotion (pp. 319-343). Hillsdale, NJ: Erlbaum.

Ekman, P., Davidson, R. J., & Friesen, W. V. (1990). The Duchenne smile: Emotional expression and brain physiology II. *Journal of Personality and Social Psychology*, *58*(2), 342–353.

Ekman, P., & Friesen, W. V. (1982). Felt, false, and miserable smiles. *Journal of Nonverbal Behavior*, *6*(4), 238–252. http://doi.org/10.1007/BF00987191

Ekman, P., Friesen, W. V, O'Sullivan, M., Chan, A., Diacoyanni-Tarlatzis, I., Heider, K., … Tomita, M. (1987). Universals and cultural differences in the judgments of facial expressions of emotion. *Journal of Personality and Social Psychology*, *53*(4), 712–717. http://doi.org/10.1037/0022-3514.53.4.712

Ekman, P., Levenson, R. W., & Friesen, W. V. (1983). Autonomic nervous system activity distinguishes among emotions. *Science*, *221*(4616), 1208–1210.

Elfenbein, H. A., & Ambady, N. (2003). Universals and cultural differences in recognizing

emotions. *Current Directions in Psychological Science*, *12*(5), 159–164. http://doi.org/10.1111/1467-8721.01252

Fischer, A. A. (1987). Pressure algometry over normal muscles. Standard values, validity and reproducibility of pressure threshold. *Pain*, *30*(1), 115–126. http://doi.org/10.1016/0304-3959(87)90089-3

Fox, N. A., & Davidson, R. J. (1988). Patterns of brain electrical activity during facial signs of emotion in 10-month old infants. *Developmental Psychology*, *24*(2), 230–236.

Frank, M. G., Ekman, P., & Friesen, W. V. (1993). Behavioral markers and recognizability of the smile of enjoyment. *Interpersonal Relations and Group Processes*, *64*(1), 83–93.

Fredrickson, B. L. (2001). The role of positive emotions in positive psychology: The broaden-and-build theory of positive emotions. *American Psychologist*, *56*(3), 218–226.

Fredrickson, B. L., & Levenson, R. W. (1998). Positive emotions speed recovery from the cardiovascular sequelae of negative emotions. *Cognition and Emotion*, *12*(2), 191–220. http://doi.org/10.1080/026999398379718

Gerber, J., & Wheeler, L. (2009). On being rejected: A meta-analysis of experimental research on rejection. *Perspectives on Psychological Science*, *4*(5), 468–488. http://doi.org/10.1111/j.1745-6924.2009.01158.x

Goldberg, L. S., & Grandey, A. A. (2007). Display rules versus display autonomy: Emotion regulation, emotional exhaustion, and task performance in a call center simulation. *Journal of Occupational Health Psychology*, *12*(3), 301–318. http://doi.org/10.1037/1076-8998.12.3.301

Gottman, J., Levenson, R., & Woodin, E. (2001). Facial expressions during marital conflict. *The Journal of Family Communication*, *1*(1), 37–57.

Green, C. R., Anderson, K. O., Baker, T. A., Campbell, L. C., Decker, S., Fillingim, R. B., … Vallerand, A. H. (2003). The unequal burden of pain: Confronting racial and ethnic disparities in pain. *Pain Medicine*, *4*(3), 277–294.

Gunnery, S. D., & Ruben, M. A. (2016). Perceptions of Duchenne and non-Duchenne smiles: A meta-analysis. *Cognition and Emotion*, *30*(3), 501–515. http://doi.org/10.1080/02699931.2015.1018817

Hass, R. G. (1984). Perspective taking and self-awareness: Drawing an E on your forehead. *Journal of Personality and Social Psychology*, *46*(4), 788–798. http://doi.org/10.1037/0022-3514.46.4.788

Hassinger, H. J., Semenchuk, E. M., & Brien, W. H. O. (1999). Cardiovascular responses to pain and stress in migraine. *Headache*, *39*(9), 605–615.

Hess, U., Kappas, A., McHugo, G. J., Lanzetta, J. T., & Kleck, R. E. (1992). The facilitative effects of facial expression on the self-generation of emotion. *International Journal of Psychophysiology*, *12*, 251–265.

Iffland, B., Sansen, L. M., Catani, C., & Neuner, F. (2014). Rapid heartbeat, but dry palms: Reactions of heart rate and skin conductance levels to social rejection. *Frontiers in Psychology*, *5*(956), 1–10. http://doi.org/10.3389/fpsyg.2014.00956

Izard, C. (1971). *The face of emotion.* New York: Appleton-Century-Crofts.

Izard, C. (1977). *Human emotions.* New York: Plenum.

James, W. (1890). *The principles of psychology.* New York: Henry Holt.

Koenig, J., Jarczok, M. N., Ellis, R. J., Hillecke, T. K., & Thayer, J. F. (2014). Heart rate variability and experimentally induced pain in healthy adults: A systematic review. *European Journal of Pain*, *18*(3), 1–14. http://doi.org/10.1002/j.1532-2149.2013.00379.x

Kraft, T. L., & Pressman, S. D. (2012). Grin and bear it: The influence of manipulated facial expression on the stress response. *Psychological Science*, *23*(11), 1372–1378. http://doi.org/10.1177/0956797612445312

LaFrance, M., Hecht, M. a, & Paluck, E. L. (2003). The contingent smile: A meta-analysis of sex differences in smiling. *Psychological Bulletin*, *129*(2), 305–334. http://doi.org/10.1037/0033-2909.129.2.305

Laird, J. (1974). Self-attribution of emotion: The effects of expressive behavior on the quality of emotional experience. *Journal of Personality and Social Psychology, 24,* 475-486.

Lang, S., Lanigan, D. T., & van der Wal, M. (1991). Trigeminocardiac reflexes: Maxillary and mandibular variants of the oculocardiac reflex. *Canadian Journal of Anaesthesia*, *38*(6), 757–760. http://doi.org/10.1007/BF03008454

Lange, C. (1885/1922). *The emotions.* In Instar Haupt (Trans.), (Originally published in Denmark, 1885). K. Dunlap (Ed.), *The emotions*. Baltimore, Md: Williams & Wilkins, 1922.

Lefkowitz, M. M., & Tesiny, E. P. (1984). Rejection and depression: Prospective and contemporaneous analyses. *Developmental Psychology*, *20*(5), 776–785. http://doi.org/10.1037/0012-1649.20.5.776

Levenson, R. W., & Ekman, P. (2002). Difficulty does not account for emotion-specific heart rate changes in the directed facial action task. *Psychophysiology*, *39*, 397–405.

Levenson, R. W., Ekman, P., & Friesen, W. V. (1990). Voluntary facial action generates emotion-specific autonomic nervous system activity. *Psychophysiology*, *27*(4), 363–384.

Lovering, S. (2006). Cultural attitudes and beliefs about pain. *Journal of Transcultural Nursing*, *17*(4), 389–395. http://doi.org/10.1177/1043659606291546

Maas, C. J., & Hox, J. (2005). Sufficient sample sizes for multilevel modeling. *Journal of Research Methods for the Behavioral and Social Sciences*, *1*, 86–92. http://doi.org/10.1027/1614-1881.1.3.86

MacDonald, G., & Leary, M. R. (2005). Why does social exclusion hurt? The relationship between social and physical pain. *Psychological Bulletin*, *131*(2), 202–223. http://doi.org/10.1037/0033-2909.131.2.202

Mandal, M. K., Asthana, H. S., & Pandey, R. (1995). Asymmetry in emotional face: Its role in intensity of expression. *The Journal of Psychology*, *129*(2), 235–241. http://doi.org/10.1080/00223980.1995.9914961

Matsumoto, D. (1987). The role of facial response in the experience of emotion: More methodological problems and a meta-analysis. *Journal of Personality and Social Psychology*, *52*(4), 769–774.

Matthews, K. A., Katholi, C. R., McCreath, H., Whooley, M. A., Williams, D. R., Zhu, S., & Markovitz, J. H. (2004). Blood pressure reactivity to psychological stress predicts hypertension in the CARDIA study. *Circulation*, *110*(1), 74–78. http://doi.org/10.1161/01.CIR.0000133415.37578.E4

Matthews, K. A., Woodall, K. L., & Allen, M. T. (1993). Cardiovascular reactivity to stress predicts future blood pressure status. *Hypertension*, *22*, 479–485. http://doi.org/10.1161/01.HYP.22.4.479

McHugh, M. L. (2012). Interrater reliability: The kappa statistic. *Biochemia Medica*, *22*(3), 276–282.

McNair, D. M., Lorr, M., & Droppelman, L. F. (1971). *Manual for the Profile of Mood States.* San Diego: Educational and Industrial Testing Services.

Melzack, R. (1999). From the gate to the neuromatrix. *Pain*, *Suppl 6*, S121–S126. http://doi.org/10.1016/S0304-3959(99)00145-1

Melzack, R., & Wall, P. D. (1965). Pain mechanisms: A new theory. *Science*, *150*, 971–979. http://doi.org/10.1016/S1082-3174(96)80062-6

Menkes, M. S., Matthews, K. A., Krantz, D. S., Lundberg, U., Mead, L. A., Qaqish, B., … Pearson, T. A. (1984). Cardiovascular reactivity to the cold pressor test as a predictor of hypertension. *Hypertension*, *6*(3), 301–306.

Moayedi, M., & Davis, K. D. (2013). Theories of pain: From specificity to gate control. *Journal of Neurophysiology*, *109*(1), 5–12. http://doi.org/10.1152/jn.00457.2012

Mueller, C., Klega, A., Buchholz, H. G., Rolke, R., Magerl, W., Schirrmacher, R., … Schreckenberger, M. (2010). Basal opioid receptor binding is associated with differences in sensory perception in healthy human subjects: A [18F]diprenorphine PET study. *NeuroImage*, *49*(1), 731–737. http://doi.org/10.1016/j.neuroimage.2009.08.033

Niedenthal, P. M., Mermillod, M., Maringer, M., & Hess, U. (2010). The Simulation of Smiles (SIMS) model: Embodied simulation and the meaning of facial expression. *Behavioral and Brain Sciences*, *33*(6), 417–480. http://doi.org/10.1017/S0140525X10000865

Noah, T., Schul, Y., & Mayo, R. (2018). When both the original study and its failed replication are correct: Feeling observed eliminates the facial-feedback effect. *Journal of Personality and Social Psychology*, *114*(5), 657–664. http://doi.org/10.1037/pspa0000121

Posner, J., Telekes, A., Crowley, D., Phillipson, R., & Peck, A. W. (1985). Effects of an opiate on cold-induced pain and the CNS in healthy volunteers. *Pain*, *23*(1), 73–82. http://doi.org/10.1016/0304-3959(85)90232-5

Pressman, S. D., Acevedo, A. M., Aucott, K., & Kraft-Feil, T. Smiling through the pain: The

effects of experimentally manipulated facial expressions during needle injection. Manuscript under review.

Price, D. D. (2000). Psychological and neural mechanisms of the affective dimension of pain. *Science*, *288*, 1769–1772.

Radloff, L. S. (1977). A self-report depression scale for research in the general population. *Applied Psychological Measurement*, *1*(3), 385–401. http://doi.org/10.1177/014662167700100306

Rainville, P. (2002). Brain mechanisms of pain affect and pain modulation. *Current Opinion in Neurobiology*, *12*, 195–204.

Rhudy, J. L., & Meagher, M. W. (2001). The role of emotion in pain modulation. *Neuropsychiatry*, *14*(3), 241–245.

Riley III, J. L., Robinson, M. E., Wise, E. A., Myers, C. D., & Fillingim, R. B. (1998). Sex differences in the perception of noxious experimental stimuli: A meta-analysis. *Pain*, *74*, 181–187.

Riva, P., Wirth, J. H., & Williams, K. D. (2011). The consequences of pain: The social and physical pain overlap on psychological responses. *European Journal of Social Psychology*, *41*(6), 681–687. http://doi.org/10.1002/ejsp.837

Rosenberg, E. L., Ekman, P., Jiang, W., Babyak, M., Coleman, E., Hanson, M., … Blumenthal, J. A. (2001). Linkages between facial expressions of anger and transient myocardial ischemia in men with coronary artery disease. *Emotion*, *1*(2), 107–115.

Russell, D. W. (1996). UCLA Loneliness Scale (Version 3): Reliability, validity, and factor structure. *Journal of Personality Assessment*, *66*(1), 20–40. http://doi.org/10.1207/s15327752jpa6601

Sherwood, A., Allen, M. T., Fahrenberg, J., Kelsey, R. M., Lovallo, W. R., & van Doornen, L. J. P. (1990). Methodological guidelines for impedance cardiography. *Psychophysiology*, *27*(1), 1–23. http://doi.org/10.1016/S0894-8321(87)80086-4

Shore, D. M., & Heerey, E. A. (2011). The value of genuine and polite smiles. *Emotion*, *11*(1), 169–174. http://doi.org/10.1037/a0022601

Slavich, G. M., Thornton, T., & Monroe, S. M. (2009). Targeted rejection predicts hastened onset of major depression. *Journal of Social and Clinical Psychology*, *28*(2), 223–243. http://doi.org/10.1521/jscp.2009.28.2.223.TARGETED

Soussignan, R. (2002). Duchenne smile, emotional experience, and autonomic reactivity: A test of the facial feedback hypothesis. *Emotion*, *2*(1), 52–74. http://doi.org/10.1037//1528-3542.2.1.52

Steptoe, A., & Wardle, J. (2011). Positive affect measured using ecological momentary assessment and survival in older men and women. *Proceedings of the National Academy of Sciences*, *108*(45), 18244–18248. http://doi.org/10.1073/pnas.1110892108

Steptoe, A., Wardle, J., & Marmot, M. (2005). Positive affect and health-related neuroendocrine, cardiovascular, and inflammatory processes. *Proceedings of the National Academy of Sciences*, *102*(18), 6508–6512. http://doi.org/10.1073/pnas.0409174102

Strack, F. (2016). Reflection on the smiling registered replication report. *Perspectives on Psychological Science*, *11*(6), 929–930. http://doi.org/10.1177/1745691616674460

Strack, F., Martin, L. L., & Stepper, S. (1988). Inhibiting and facilitating conditions of the human smile: A nonobtrusive test of the facial feedback hypothesis. *Journal of Personality and Social Psychology*, *54*(5), 768–777.

Stroud, L. R., Tanofsky-Kraff, M., Wilfley, D. E., & Salovey, P. (2000). The Yale Interpersonal

Stressor (YIPS): Affective, physiological, and behavioral responses to a novel interpersonal rejection paradigm. *Annals of Behavioral Medicine*, *22*(3), 204–213.

Sullivan, M. J. L., Bishop, S. R., & Pivik, J. (1995). The Pain Catastrophizing Scale: Development and validation. *Psychological Assessment*, *7*(4), 524–532. http://doi.org/10.1037/1040-3590.7.4.524

Terkelsen, A. J., Molgaard, H., Hansen, J., Andersen, O. K., & Jensen, T. S. (2005). Acute pain increases heart rate: Differential mechanisms during rest and mental stress. *Autonomic Neuroscience: Basic and Clinical*, *121*(1–2), 101–109. http://doi.org/10.1016/j.autneu.2005.07.001

Thayer, J. F., Åhs, F., Fredrikson, M., Sollers, J. J., & Wager, T. D. (2012). A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. *Neuroscience and Biobehavioral Reviews*, *36*(2), 747–756. http://doi.org/10.1016/j.neubiorev.2011.11.009

Thibault, P., Levesque, M., Gosselin, P., & Hess, U. (2012). The Duchenne marker is not a universal signal of smile authenticity - but it can be learned! *Social Psychology*, *43*(4), 215–221. http://doi.org/10.1027/1864-9335/a000122

Tomkins, S. S. (1962). *Affect, imagery, consciousness:* Vol. 1. *The positive affects.* New York: Springer.

Tourangeau, R., & Ellsworth, P. C. (1979). The role of facial response in the experience of emotion. *Journal of Personality and Social Psychology*, *37*(9), 1519–1531. http://doi.org/10.1037/0022-3514.37.9.1519

Tsai, J. L., Louie, J. Y., Chen, E. E., & Uchida, Y. (2007). Learning what feelings to desire: Socialization of ideal affect through children's storybooks. *Personality and Social*

Psychology Bulletin, *33*(1), 17–30. http://doi.org/10.1177/0146167206292749

Usala, P. D. & Hertzog, C. (1989). Measurement of affective states in adults: Evaluation of an adjective rating scale instrument. *Research on Aging, 11,* 403-426.

Wagenmakers, E.-J., Beek, T., Dijkhoff, L., Gronau, Q. F., Acosta, A., Adams, R. B., … Zwaan, R. A. (2016). Registered replication report: Strack, Martin, & Stepper (1988). *Perspectives on Psychological Science*, *11*(6), 917–928. http://doi.org/10.1177/1745691616674458

Wagner, D. T., Barnes, C. M., & Scott, B. A. (2014). Driving it home: How workplace emotional labor harms employee home life. *Personnel Psychology*, *67*(2), 487–516. http://doi.org/10.1111/peps.12044

Williams, Kippling, D., Cheung, C. K. T., & Choi, W. (2000). Cyberostracism: Effects of being ignored over the Internet. *Journal of Personality and Social Psychology*, *79*(5), 748–762. http://doi.org/10.1037/0022-3514.79.5.748

Williams, K. D., Govan, C. L., Croker, V., Tynan, D., Cruickshank, M., & Lam, A. (2002). Investigations into differences between social- and cyberostracism. *Group Dynamics: Theory, Research, and Practice*, *6*(1), 65–77. http://doi.org/10.1037//1089-2699.6.1.65

Williamson, T. J., Thomas, K. M. S., Eisenberger, N. I., & Stanton, A. L. (2018). Effects of social exclusion on cardiovascular and affective reactivity to a socially evaluative stressor. *International Journal of Behavioral Medicine*, *25*(4), 410–420. http://doi.org/10.1007/s12529-018-9720-5

Yong, H. H., Bell, R., Workman, B., & Gibson, S. J. (2003). Psychometric properties of the Pain Attitudes Questionnaire (revised) in adult patients with chronic pain. *Pain*, *104*(3), 673–681. http://doi.org/10.1016/S0304-3959(03)00140-4

Zellner, A. (1962). An efficient method of estimating seemingly unrelated regressions and tests

for aggregation bias. *Journal of the American Statistical Association*, *57*(298), 348–368.