Autism, the predictive brain and interoception

Peter Vermeulen, PhD

AUTISM in CONTEXT

from neurodiversity to neuroharmony

3. Nationaler Autismus Kongress
7./8. November 2025, Kursaal Interlaken

autismus schweiz
autisme suisse
autismo svizzera

Our 8th sense

AUTISM in CONTEXT

from neurodiversity to neuroharmony

PHILOSOPHICAL TRANSACTIONS B

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Introduction

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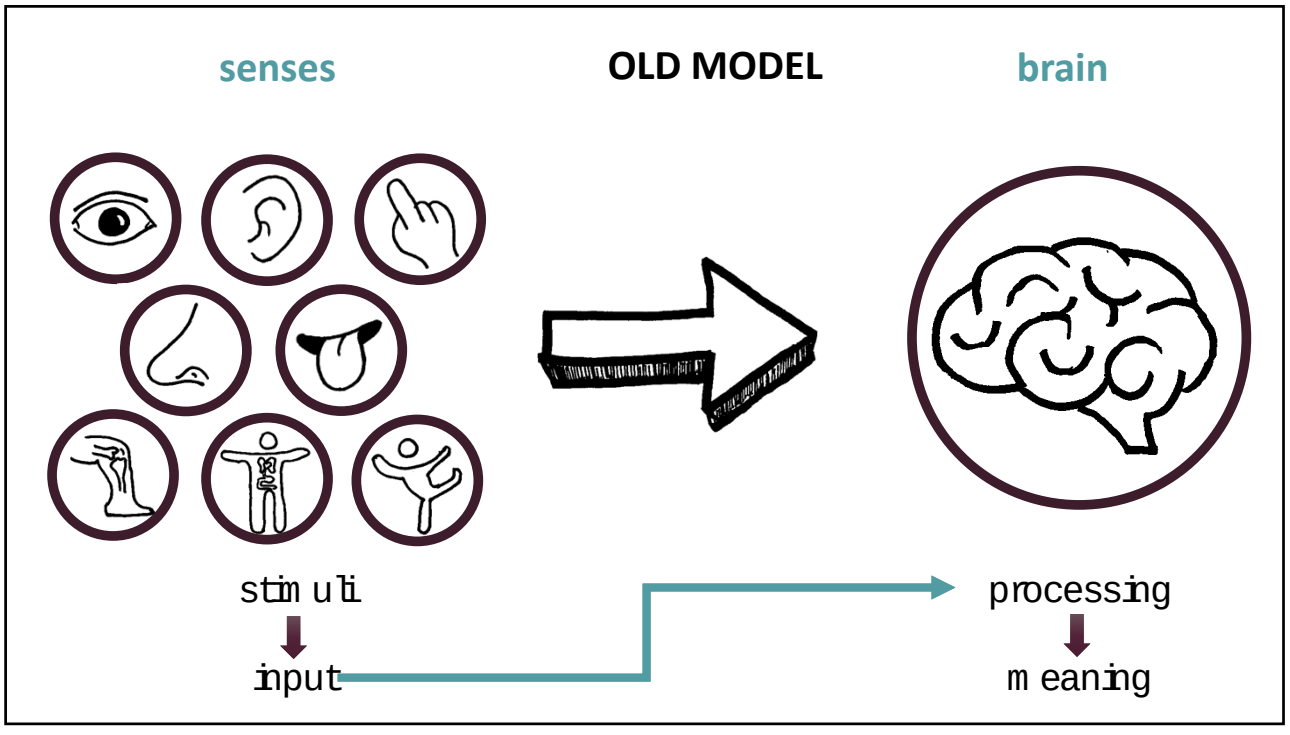
One contribution of 16 to a theme issue 'Interoception beyond homeostasis: affect, cognition and mental health'.

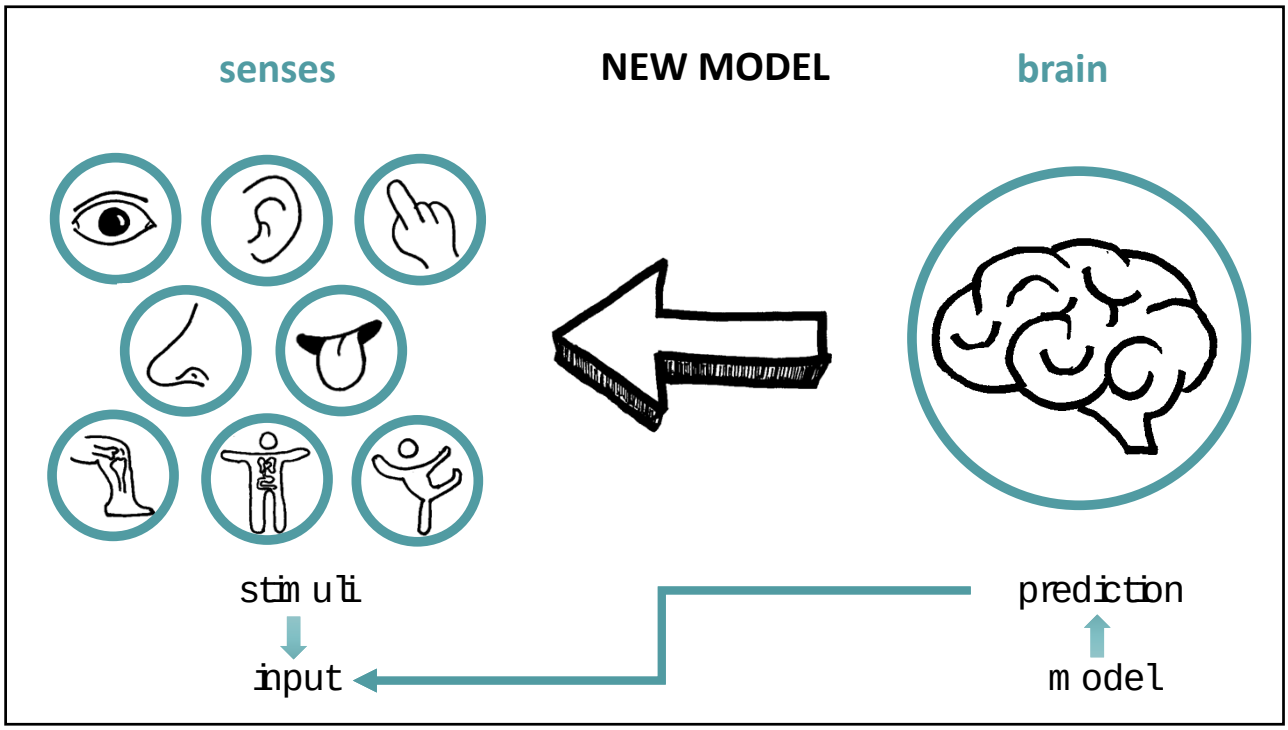
Interoception beyond homeostasis: affect, cognition and mental health

Manos Tsakiris[1,†] and Hugo Critchley[2,3,†]

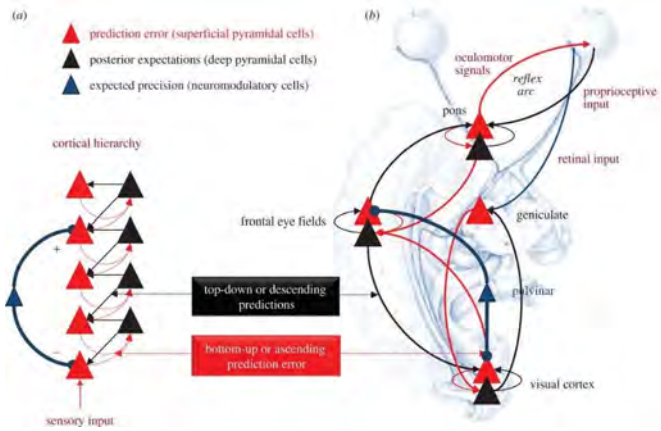
[1]Laboratory of Action and Body, Department of Psychology, Royal Holloway, University of London, Egham TW20 0EX, UK
[2]Psychiatry Group, Department of Neuroscience, Brighton and Sussex Medical School, Universities of Sussex and Brighton, Brighton BN1 9PX, UK
[3]Sackler Centre for Consciousness Science, University of Sussex, Brighton BN1 9RH, UK

Interoception refers to the sensing of the internal state of one's body. Interoception is distinct from the processing of sensory information concerning external (non-self) stimuli (e.g. vision, hearing, touch and smell) and is the afferent axis to internal (autonomic and hormonal) physiological control. However, the impact of interoception extends beyond homeostatic/allostatic reflexes: it is proposed to be fundamental to motivation, emotion (affective feelings and behaviours), social cognition and self-awareness. This view is supported by a growing body of experimental evidence that links peripheral physiological states to mental processes. Within this framework, the representation of self is constructed from early development through continuous integrative representation of biological data from the body, to form the basis for those aspects of conscious awareness grounded on the subjective sense of being a unique individual. This theme issue of the *Philosophical Transactions*





The brain does not process stimuli, only what is different from the stimuli it predicted…



From *The Lancet*

Prediction errors

- The brain has only one goal:
  helping us to survive by predicting the sensory input and minimizing prediction errors, either by learning or by changing the world
- The brain doesn't like prediction errors (they cause stress)
- The brain knows it cannot avoid all prediction errors. Therefore, it uses **a variable precision** in handling prediction errors

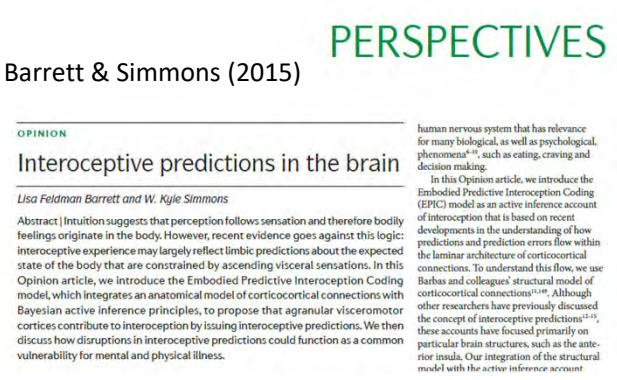
Depending on the **context** the brain will treat a prediction error as noise (irrelevant) or signal (relevant)

- If relevant, this leads to learning or action

EPIC: Embodied Predictive Interoception Coding

Interoceptive prediction errors signal the occurrence of discrepancies within the body, which the brain attempts to minimize

Barrett & Simmons (2015)


PERSPECTIVES

OPINION

Interoceptive predictions in the brain

Lisa Feldman Barrett and W. Kyle Simmons

Abstract | Intuition suggests that perception follows sensation and therefore bodily feelings originate in the body. However, recent evidence goes against this logic: interoceptive experience may largely reflect limbic predictions about the expected state of the body that are constrained by ascending visceral sensations. In this Opinion article, we introduce the Embodied Predictive Interoception Coding model, which integrates an anatomical model of corticocortical connections with Bayesian active inference principles, to propose that agranular visceromotor cortices contribute to interoception by issuing interoceptive predictions. We then discuss how disruptions in interoceptive predictions could function as a common vulnerability for mental and physical illness.

human nervous system that has relevance for many biological, as well as psychological, phenomena[6–10], such as eating, craving and decision making.

In this Opinion article, we introduce the Embodied Predictive Interoception Coding (EPIC) model as an active inference account of interoception that is based on recent developments in the understanding of how predictions and prediction errors flow within the laminar architecture of corticocortical connections. To understand this flow, we use Barbas and colleagues' structural model of corticocortical connections[11,10]. Although other researchers have previously discussed the concept of interoceptive predictions[12–15], these accounts have focused primarily on particular brain structures, such as the anterior insula. Our integration of the structural model with the active inference account

Autism, the predictive mind and context

- In autism the flexible adjustment in function of context of predictions and the weight given to prediction error seems to be affected
- HIPPEA:

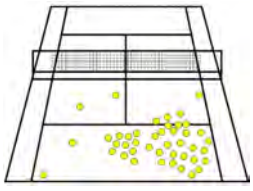
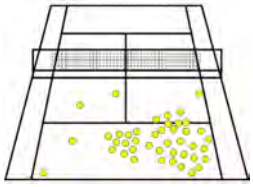
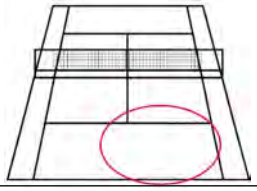
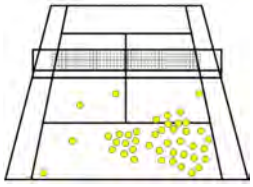
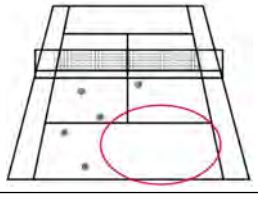
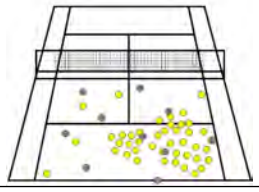
  High, Inflexible Precision of Prediction Errors in Autism
  (Van de Cruys a.o., 2013, 2014)

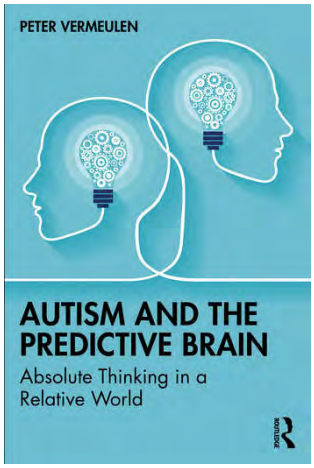
Psychological Review
2014, Vol. 121, No. 4, 649–675

0033-295X/14/$12.00 http://dx.doi.org/10.1037/a0037665

Precise Minds in Uncertain Worlds: Predictive Coding in Autism

Sander Van de Cruys, Kris Evers, Ruth Van der Hallen, Lien Van Eylen,
Bart Boets, Lee de-Wit, and Johan Wagemans
KU Leuven

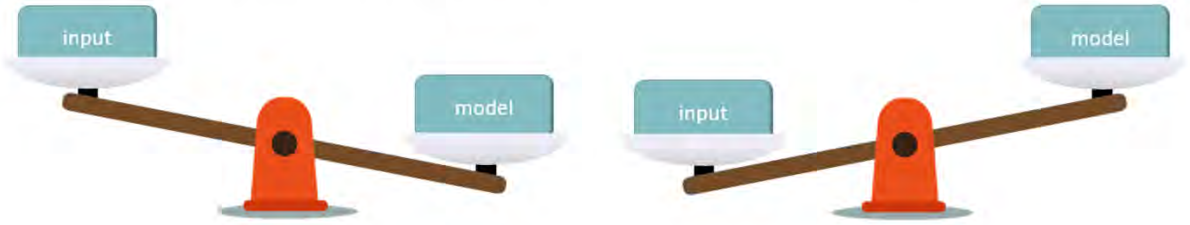
©Peter Vermeulen	Non autistic brain: Relative thinking	Autistic brain: Absolute thinking
Where the balls land		
Prediction		
Prediction errors		



Absolute thinking in a relative world

The balance of uncertainty

Autism



Basic problem in autism:

UNCERTAINTY

Nothing has an absolute meaning

Uncertainty, sensory issues and distress

brain sciences
MDPI

Article

Autistic Sensory Traits and Psychological Distress: Mediating Role of Worry and Intolerance of Uncertainty

Patricia Recio [1,2], Pilar Pozo [1,2], Cristina García-López [2,3,4] and Encarnación Sarriá [1,2,*]

1 Department of Methodology of Behavioral Sciences, Faculty of Psychology, National University for Distance Education (UNED), 28040 Madrid, Spain; reciop@psi.uned.es (P.R.); ppozo@psi.uned.es (P.P.)
2 IMIENS: Joint Research Institute UNED-Health Institute Carlos III, 28029 Madrid, Spain; cristina.garcial@sjd.es
3 Learning Disabilities Unit (UTAE), Neuropediatrics Department, Hospital Sant Joan de Déu, 08950 Barcelona, Spain
4 Psychology Department, Faculty of Health Sciences, University Abat Oliba CEU, 08022 Barcelona, Spain
* Correspondence: esarria@psi.uned.es

Interoception: different dimensions

Biological Psychology 104 (2015) 65–74

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

ELSEVIER

Knowing your own heart: Distinguishing interoceptive accuracy from interoceptive awareness

CrossMark

Sarah N. Garfinkel [a,b,*], Anil K. Seth [b,c], Adam B. Barrett [b,c], Keisuke Suzuki [b,c], Hugo D. Critchley [a,b]

[a] Psychiatry, Brighton and Sussex Medical School, UK
[b] Sackler Centre for Consciousness Science, University of Sussex, UK
[c] Department of Informatics, University of Sussex, UK

Interoception: different dimensions

- ***Accuracy***: how accurate are you in detecting and tracking internal bodily sensations?
- ***Sensibility***: subjective measure of focus on internal bodily sensations
- ***Awareness***: metacognitive awareness of interoceptive accuracy

Original Article

autism

Autism spectrum disorder and interoception: Abnormalities in global integration?

Timothy R Hatfield[1], Rhonda F Brown[1], Melita J Giummarra[2] and Bigna Lenggenhager[3]

Autism
1–11
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Journal of Autism and Developmental Disorders
https://doi.org/10.1007/s10803-019-04279-4

ORIGINALPAPER

Dissociation in How Core Autism Features Relate to Interoceptive Dimensions: Evidence from Cardiac Awareness in Children

E. R. Palser[1,2,5] · A. Fotopoulou[1] · E. Pellicano[3,4] · J. M. Kilner[2]

AUTISM in CONTEXT from neurodiversity to neuroharmony

Reduced interoceptive accuracy

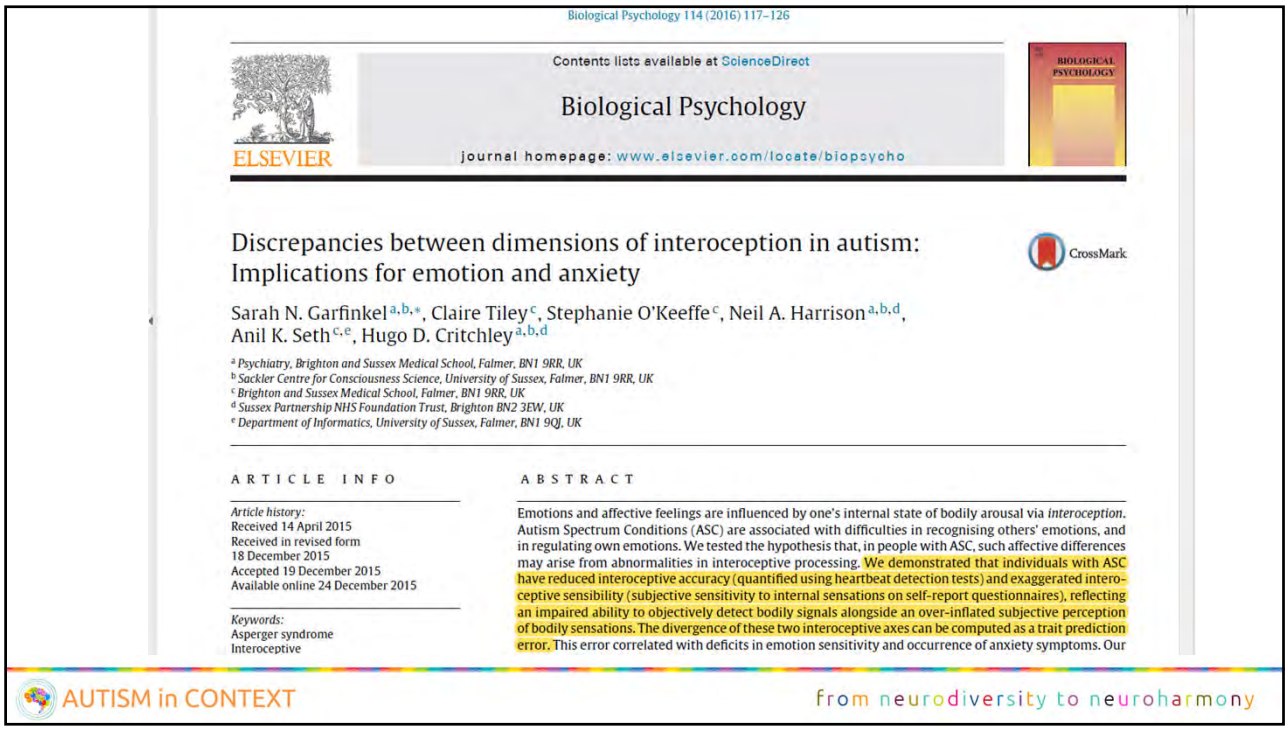
Published in final edited form as:
J Autism Dev Disord. 2023 March ; 53(3): 947–962. doi:10.1007/s10803-022-05656-2.

Characterizing Interoceptive Differences in Autism: A Systematic Review and Meta-analysis of Case-control Studies

Zachary J. Williams[1,2,3,4,5,*], Evan Suzman[6,*], Samantha L. Bordman[7], Jennifer E. Markfeld[2], Sophia M. Kaiser[8], Kacie A. Dunham[2,3], Alisa R. Zoltowski[3], Michelle D. Failla[9], Carissa J. Cascio[3,4,5,10], Tiffany G. Woynaroski[2,3,4,5]

Interoception in autism

- Low cardiac awareness
  (Garfinkel a.o., 2016; Palser a.o., 2019)
- Reduced awareness of hunger, thirst, pain, full bladder or bowel movements
- Alexithymia



Biological Psychology 114 (2016) 117–126

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Discrepancies between dimensions of interoception in autism: Implications for emotion and anxiety

Sarah N. Garfinkel[a,b,*], Claire Tiley[c], Stephanie O'Keeffe[c], Neil A. Harrison[a,b,d], Anil K. Seth[c,e], Hugo D. Critchley[a,b,d]

[a] Psychiatry, Brighton and Sussex Medical School, Falmer, BN1 9RR, UK
[b] Sackler Centre for Consciousness Science, University of Sussex, Falmer, BN1 9RR, UK
[c] Brighton and Sussex Medical School, Falmer, BN1 9RR, UK
[d] Sussex Partnership NHS Foundation Trust, Brighton BN2 3EW, UK
[e] Department of Informatics, University of Sussex, Falmer, BN1 9QJ, UK

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ABSTRACT

Emotions and affective feelings are influenced by one's internal state of bodily arousal via *interoception*. Autism Spectrum Conditions (ASC) are associated with difficulties in recognising others' emotions, and in regulating own emotions. We tested the hypothesis that, in people with ASC, such affective differences may arise from abnormalities in interoceptive processing. We demonstrated that individuals with ASC have reduced interoceptive accuracy (quantified using heartbeat detection tests) and exaggerated interoceptive sensibility (subjective sensitivity to internal sensations on self-report questionnaires), reflecting an impaired ability to objectively detect bodily signals alongside an over-inflated subjective perception of bodily sensations. The divergence of these two interoceptive axes can be computed as a trait prediction error. This error correlated with deficits in emotion sensitivity and occurrence of anxiety symptoms. Our

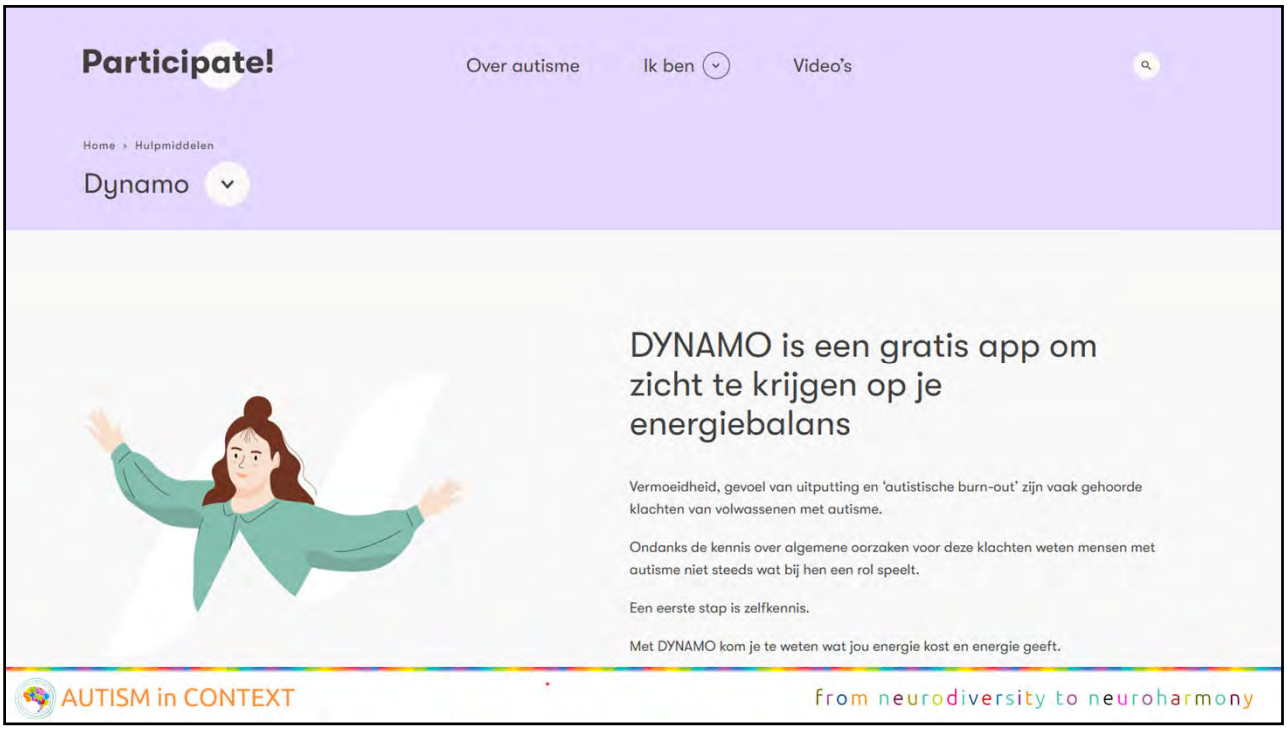
Consequences of low interoceptive accuracy

- Difficulties with '**body budgeting**' (Lisa Feldman Barrett)
  - Drinking
  - Eating
  - Moving
  - Monitoring energy level
  - Sleeping

Recommended strategies

- Support for monitoring physiological needs:
  - Health apps
  - Smart watches

AUTISM in CONTEXT from neurodiversity to neuroharmony



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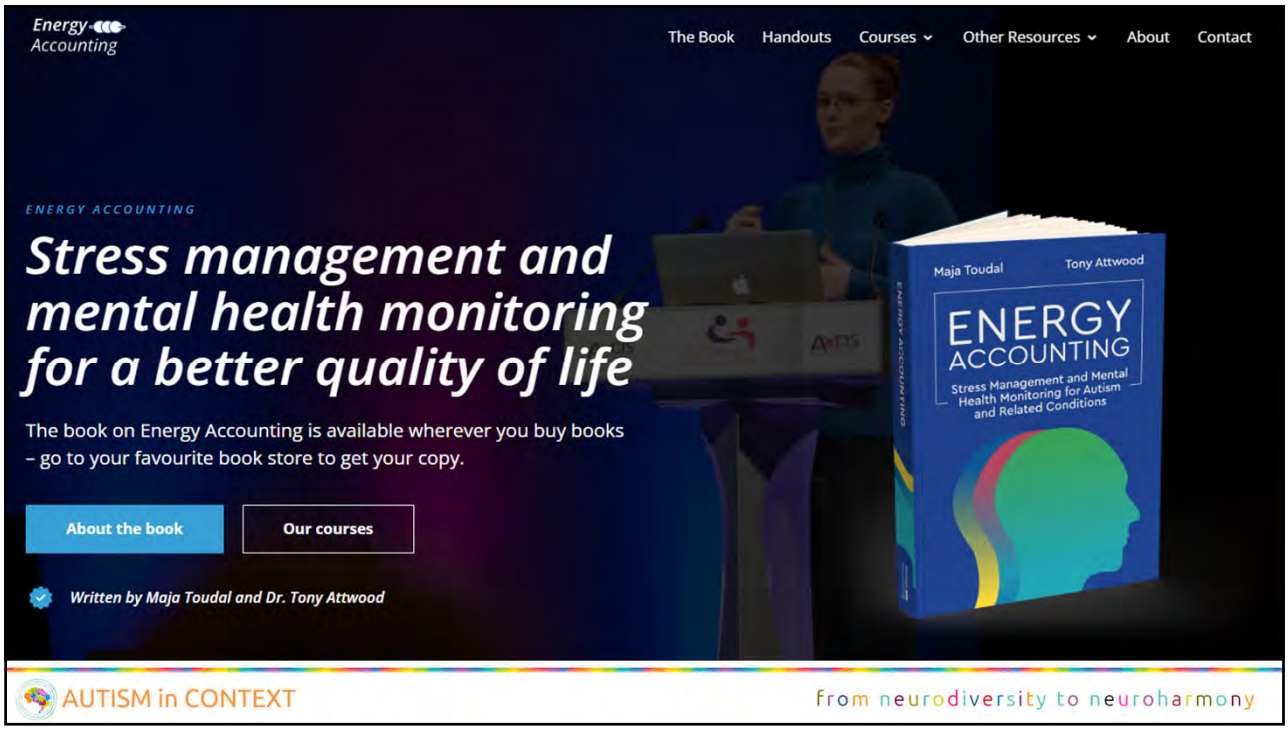
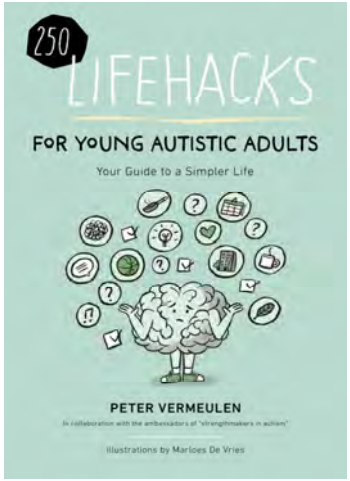


Tips for energy, eating and sleeping



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from neurodiversity to neuroharmony

Recommended strategies

- Good planning and/or predictable routines for:
  - Breaks
  - Eating and drinking
  - Use of toilet
  - Going to bed in time

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Consequences of low interoceptive accuracy

Difficulties with

- **Emotion recognition**
- **Emotion regulation**
- **Self-understanding**

AUTISM in CONTEXT from neurodiversity to neuroharmony

OXFORD

Social Cognitive and Affective Neuroscience, 2017, 1–23

doi: 10.1093/scan/nsw154
Advance Access Publication Date: 19 October 2016
Original article

The theory of constructed emotion: an active inference account of interoception and categorization

Lisa Feldman Barrett[1,2,3]

[1]Department of Psychology, Northeastern University, Boston, MA, USA, [2]Athinoula, A. Martinos Center for Biomedical Imaging and [3]Psychiatric Neuroimaging Division, Department of Psychiatry, Massachusetts General Hospital and Harvard Medical School, Charlestown, MA, USA.

Correspondence should be addressed to Lisa Feldman Barrett. Department of Psychology, Northeastern University, Boston, MA, USA. E-mail: l.barrett@neu.edu

What makes it so difficult to recognize emotions?

- Necessary for making good guesses:
  - Knowledge about your body and the signals it sends to your brain: interoceptive abilities
  - Using **context** when interpreting the bodily signals

"Over-, under- en misfirings"

Williams, D. (1996). Autism: an inside-out approach. London: Jessica Kingsley Publishers

Donna Williams

AUTISM in CONTEXT from neurodiversity to neuroharmony

Not knowing what an emotion is…

"I don't know if I have fallen in love before…"

I do have all kind of sensations, but the problem is cognitive: knowing what they mean…

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Recognizing emotions

- So, knowing the *names* of emotions is not enough
- You need to be able to connect the words to
  - bodily signals
  - events
  - experiences

In other words, to **context**

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Recommended strategies

- Supported monitoring (health apps)
- Good planning and/or predictable routines for eating, drinking, toilet, sleeping
- Co-monitoring and co-regulation
- Teaching how to read own body

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Improving interoception

- Body scan does not work well with many autistic people
  - Too abstract and too vague
  - Requires focus and good attention span
  - Is a-contextual
  - Feels only safe if you already have a good relationship with your body

Based on the work of Kelly Mahler

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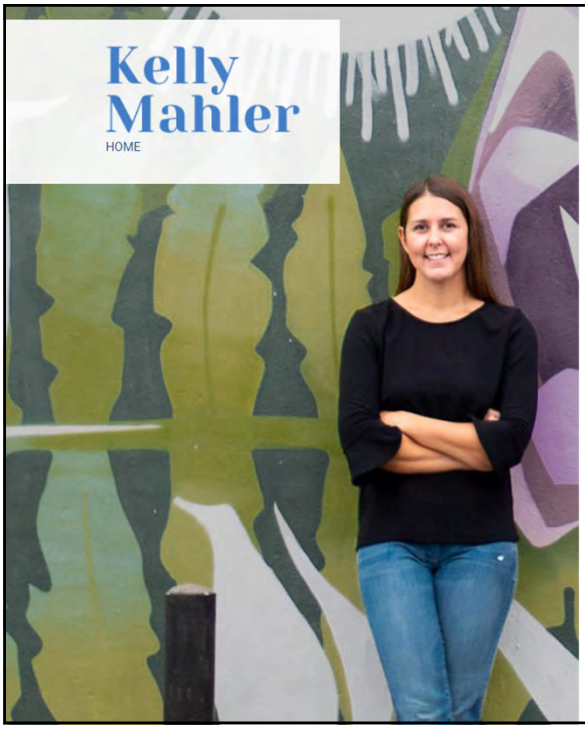

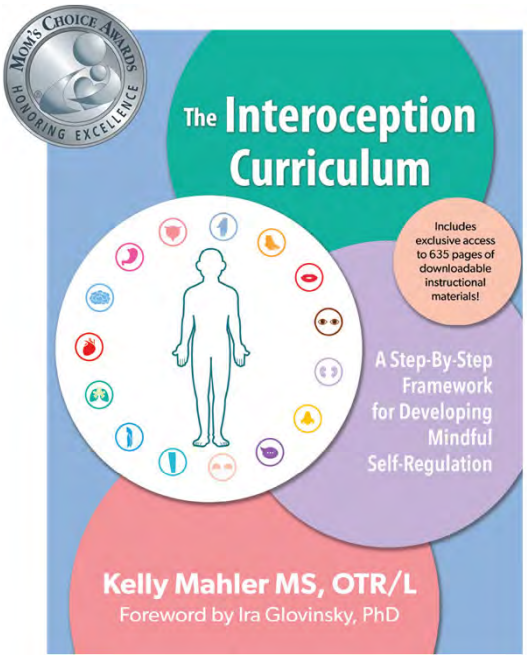

3 levels of teaching interoception

- Learning to notice body signals: *What do I feel? How does my body (part) feel?*
- Learning to make sense of the body signal: *What does what I feel mean? Link to emotion? What do I need?*
- Learning to regulate body signals: *What does my body need to feel good?*

Notice

Connect

Regulate

Source: Kelly Mahler

AUTISM in CONTEXT from neurodiversity to neuroharmony

Tips and tricks

- Individualise
- This is learning. The person should be in the learning zone
- Socratic method – Sherlock Holmes: curiosity
- All signals and emotions are good and helpful
- Recognizing is easier than identifying
- Keep it concrete
- Have fun!

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Teaching interoception

- In the context (daily activities)
- Experiments
- Games

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Heart

- Run in place for a full minute with really high knees. How does your heart feel after you have done this?
- Quest: where on your body do you feel your heartbeat?

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Lungs

- Breathe in and out five times quickly. How do your lungs feel?
- Competition: who can hold their breath the longest? Variant: who can say 'aa' the longest?

AUTISM in CONTEXT from neurodiversity to neuroharmony

Research Article

Impact of an Interoception-Based Program on Emotion Regulation in Autistic Children

Kelly Mahler,[1,2] Kerri Hample,[1] Claudia Jones,[1] Joseph Sensenig,[1] Phoebe Thomasco,[1] and Claudia Hilton[3]

[1]*Elizabethtown College, Elizabethtown, Pennsylvania, USA*
[2]*Mahler Occupational Therapy, Elizabethtown, Pennsylvania, USA*
[3]*University of Texas Medical Branch, Galveston, Texas, USA*

Correspondence should be addressed to Claudia Hilton; clhilton@utmb.edu

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Academic Editor: Kuan Lin Chen

Purpose. The aim of this study was to determine the feasibility and effectiveness of a 25-week school-based intervention and its ability to improve interoception and emotion regulation in an autistic pediatric population. *Method.* One-group pre- and posttest design implementing *The Interoception Curriculum: A Guide to Developing Mindful Self-Regulation* in a self-contained school. Participants were 14 (11 male, 3 female) students between 9 and 19 years old. The Behavior Rating Inventory of Executive Function 2 (BRIEF-2) and the Caregiver Questionnaire for Interoceptive Awareness-2nd Edition (CQIA-2) were used to determine changes in interoceptive awareness and emotion regulation. *Results.* Statistically significant improvements were found between the preintervention and postintervention scores for both interoceptive awareness and emotion regulation. *Conclusion.* This was the first study to examine the Interoception Curriculum in its entirety, providing evidence that the use of the Interoception Curriculum is feasible in a school setting and suggests that this intervention is effective for improvement of interoception. Findings also suggest that this improvement in interoception is related to improvement in emotional regulation for an autistic pediatric population.

AUTISM in CONTEXT from neurodiversity to neuroharmony

Physical exercise and interoception

Autism in Adulthood, Vol. 1, No. 3 | Perspective

Physical Activity for Autistic Adults: Recommendations for a Shift in Approach

Rachel Hallett

Published Online: 11 Sep 2019 | https://doi.org/10.1089/aut.2019.0016

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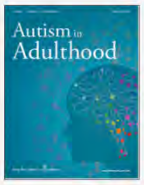
Figures References Related Details



Information

Abstract

What does existing research show?

Research so far has consisted of small studies, and the designs have often been poor. There is a tendency to overlook the well-being of autistic people and to focus on stopping certain behaviors without recognizing why they are happening, or that they may be helpful for autistic people. Studies found that physical activity has many benefits for autistic people, such as increasing well-being, helping with emotional regulation, improving walking gait and balance, and raising activity levels. However, most studies did not look at health and fitness outcomes and were more focused on outcomes that have not been identified as important to autistic people.

Physical exercise and interoception

Journal of Autism and Developmental Disorders
https://doi.org/10.1007/s10803-020-04418-2

BRIEF REPORT

Check for updates

Brief Report: Impact of a Physical Exercise Intervention on Emotion Regulation and Behavioral Functioning in Children with Autism Spectrum Disorder

Andy C. Y. Tse[1]

Abstract
Problems with emotion regulation and behavior are often reported in children with autism spectrum disorders (ASD). This pilot study examined the effect of physical exercise on emotion regulation and behavioral functioning in children with ASD. Twenty-seven children aged 8–12 years were randomized into either an exercise intervention group (n = 15) or a control group (n = 12). The intervention group received a 12-week jogging intervention. Children's parents completed the Emotion Regulation Checklist and the Child Behavior Checklist pre- and post-intervention. The intervention group demonstrated significant improvement in emotion regulation and reduction in behavioral problems ($ps < .05$). Future studies should explore the mechanisms underlying the effects of physical exercise on emotion regulation and behavior in children with ASD.

Recognize and validate their unique inner experience

- There are no bad thoughts or wrong feelings
- It is OK for think differently
- It is OK to feel differently
- '**Normal**' does not exist in minds
- It is OK ***not*** to know

AUTISM in CONTEXT from neurodiversity to neuroharmony

Yes-, no- and doubt-feelings

YES FEELING 	NO FEELING 	DOUBT FEELING 
When something happens that you like	When something happens that you don't like	When something happens and you don't know whether you like it or not
When something happens that makes you feel good	When something happens that makes you feel bad	You don't know if it is good or bad
My example:	My example:	My example:

AUTISM in CONTEXT from neurodiversity to neuroharmony

THANK YOU
FOR YOUR ATTENTION!

AUTISM in CONTEXT

from neurodiversity to neuroharmony

www.petervermeulen.be