MENTAL STATE MONITORING

Anne-Marie Brouwer

TNO innovation for life

BCI

- As a way to ‘actively’ control systems
- As an additional source of information

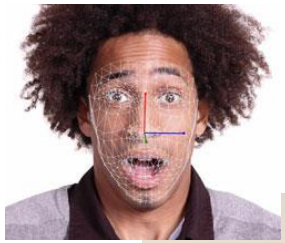
Brouwer, A.-M., & van Erp, J.B.F. (2010). A tactile P300 Brain-Computer Interface. Frontiers in Neuroscience, 4:19.

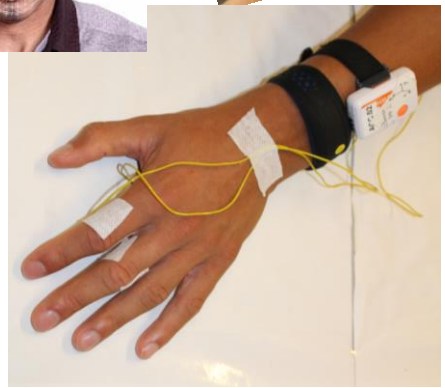
BCI

- As a way to ‘actively’ control systems
- As an additional source of information

BCI/AFFECTIVE COMPUTING

- As a way to ‘actively’ control systems
- As an additional source of information





EXPLOITING PHYSIOLOGICAL MEASURES AS A SOURCE OF INFORMATION ABOUT MENTAL STATE

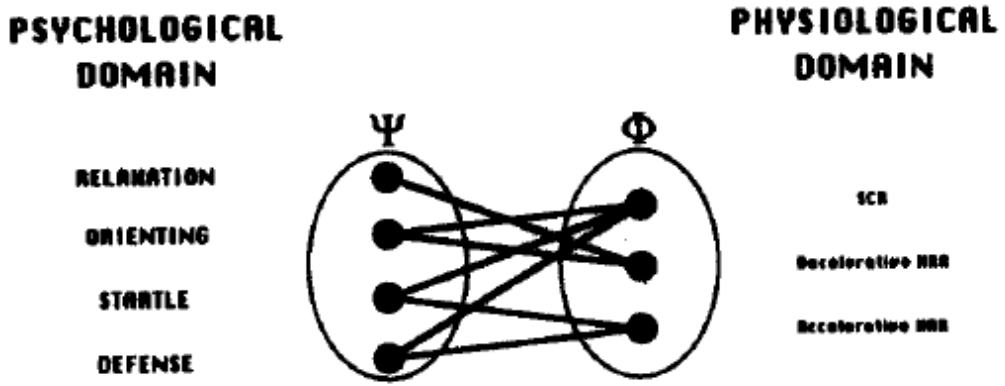
Specific advantages of physiological measures:

- Continuous information
- No distraction
- Verbal reports could be distorted

CHALLENGES

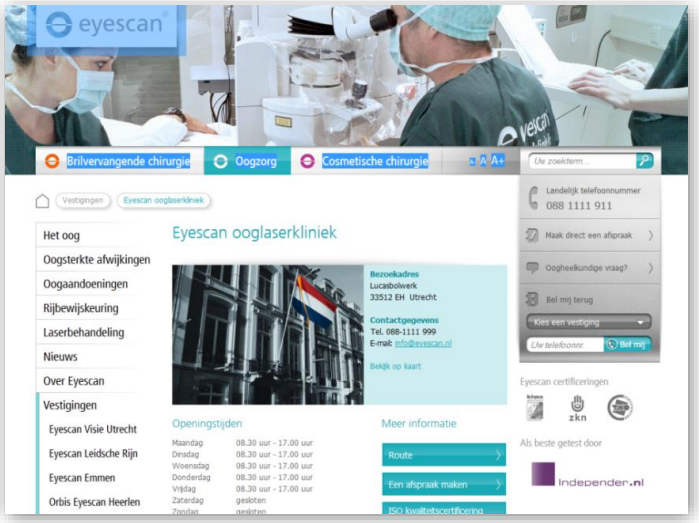
1. No simple mapping between physiology and mental state - generalization
2. Effects of body movement on physiology, unrelated to mental state
3. How can our (imperfect) estimates add value

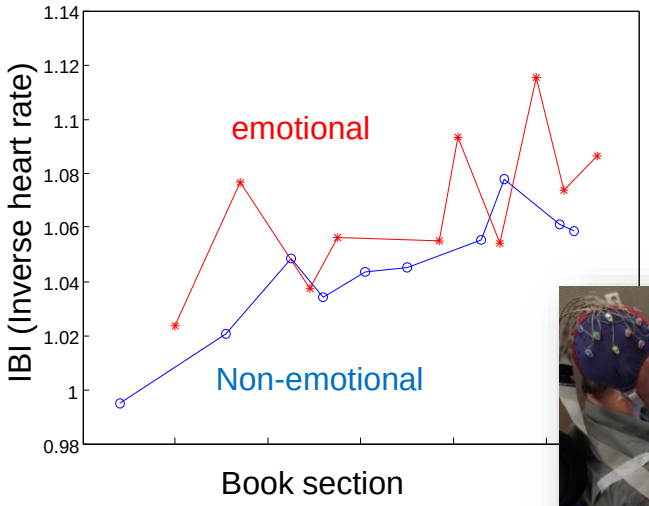
1. MAPPING CHALLENGE

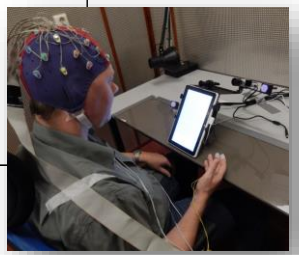


Cacioppo & Tassinary (1990). Inferring psychological significance from physiological signals. Am Psychol. 45(1):16-28.

1. MAPPING CHALLENGE







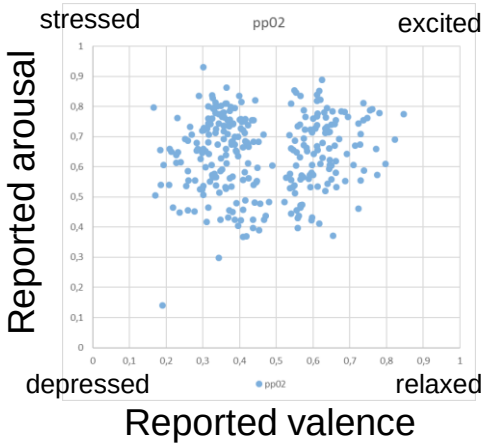
Hogervorst, Brouwer & Vos (2013) Physiological correlates of stress in individuals about to undergo eye laser surgery. Humaine Association Conference on Affective Computing and Intelligent Interaction, 473-478

Brouwer, Hogervorst, Reuderink, van der Werf, van Erp (2015) Physiological signals distinguish between reading emotional and non-emotional sections in a novel. *Brain-Computer Interfaces, 2*, 76-89.

1. MAPPING CHALLENGE

Approaches to deal with this challenge

- Model with data coming from context that is similar to context of interest



Brouwer, van de Water, Hogervorst, Kraaij, Schraagen, Hogenelst, K. (in press) Monitoring mental state during real life office work. Lecture Notes on Computer Science series (LNCS), Symbiotic 2017

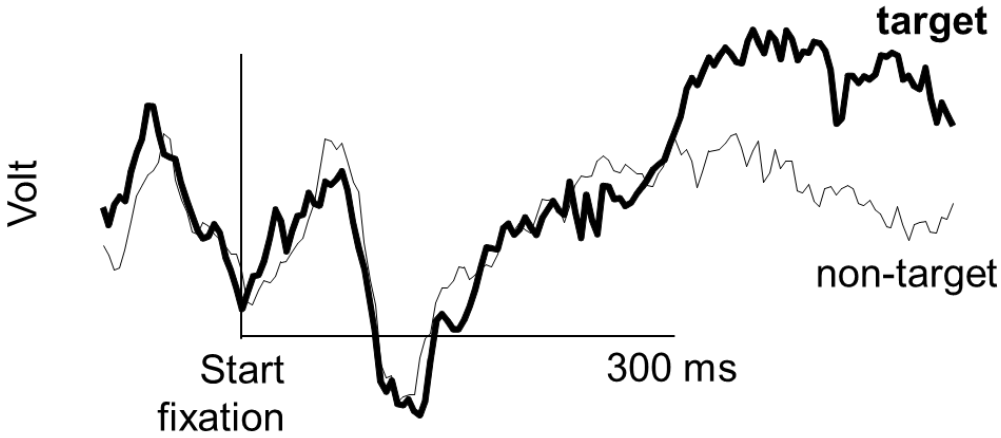
1. MAPPING CHALLENGE

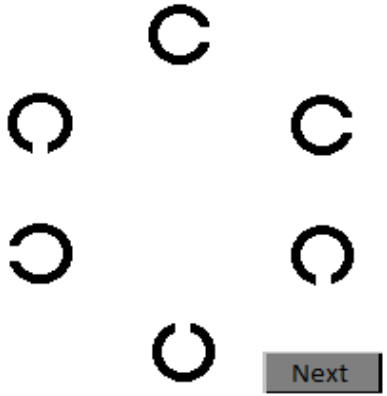
Approaches to deal with this challenge

- Model with data coming from context that is similar to context of interest
- Robust building blocks (e.g. attended events elicit P300)

FIXATION LOCKED ERPS - ATTENTION

- Distinguishing target from non-target fixation locked ERPs





Brouwer, Reuderink, Vincent, van Gerven & van Erp (2013). Distinguishing between target and nontarget fixations in a visual search task using fixation-related potentials. *Journal of Vision*, 13(3):17, 1–10.

Brouwer, Hogervorst, Oudejans, Ries, Touryan (2017) EEG and Eye Tracking Signatures of Target Encoding during Structured Visual Search. Front. Hum. Neurosci. 11:264

FIXATION LOCKED ERPS - ATTENTION

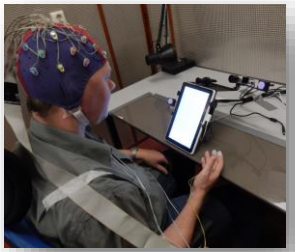
- Possible to generalize across participants and set-ups using deep learning

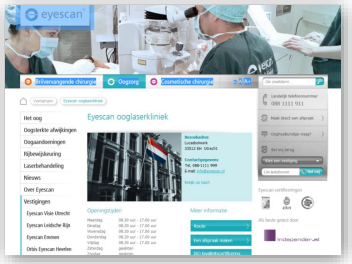
Solon, Gordon, Lawhern, Lance (2017) A generalized deep learning framework for cross-domain learning in Brain Computer Interfaces. The First Biannual Neuroadaptive Technology Conference, 34-35

2. BODY MOVEMENT CHALLENGE

Approaches to deal with this challenge

- Limit body movement





PHYSIOLOGICAL EFFECTS OF ACUTE STRESS

Inducing stress..

- Without confounds of body movements
- Strongly but ethically
- Easily and repeatable

Sing-a-Song Stress Test

Upright vacuum cleaners are common in Britain, but very unusual in Continental Europe

60

59

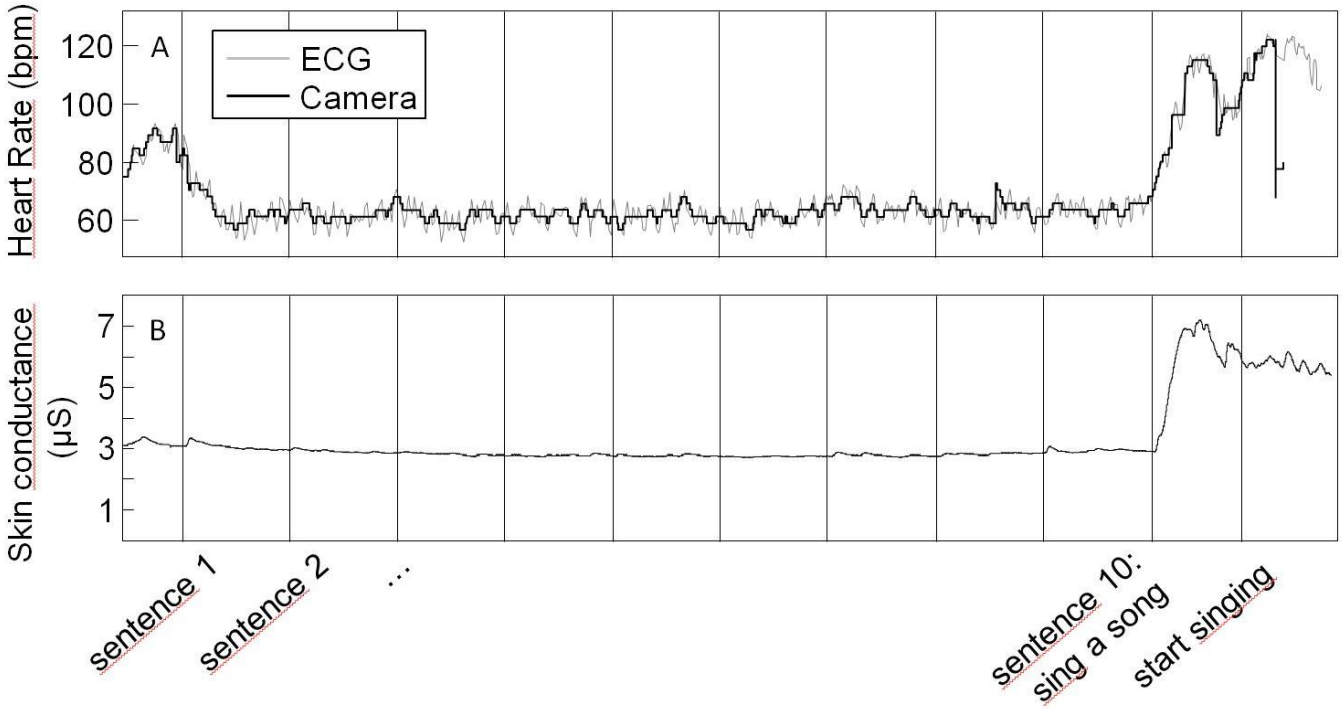
58

When the counter reaches zero, start singing a song

Strong effects on

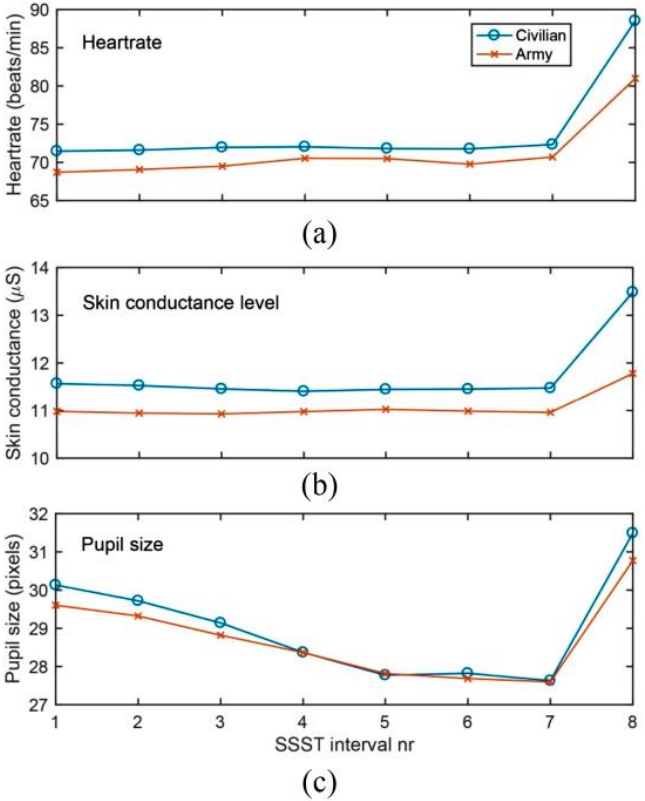
- Heart rate
- Skin conductance
- Pupil size

Tool to validate wearables



Brouwer, A.-M, Hogervorst, M. A. (2014). A new paradigm to induce mental stress: The Sing-a-Song Stress Test (SSST). Front. Neurosci. 8:224.

- Defense personell shows smaller stress responses than civilians



Toet, Bijlsma, Brouwer (2017). Stress response and facial trustworthiness judgements in civilians and military. SAGE Open, July-September 2017:1-11.

2. BODY MOVEMENT CHALLENGE

Approaches to deal with this challenge

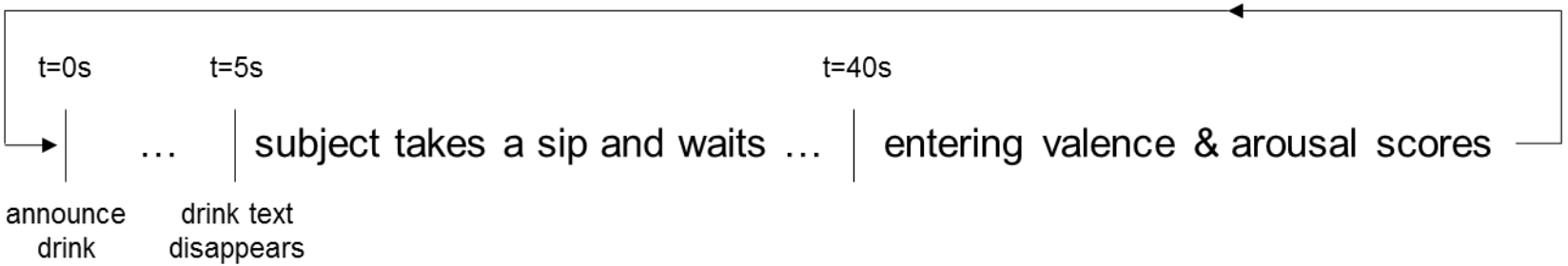
- Limit body movement

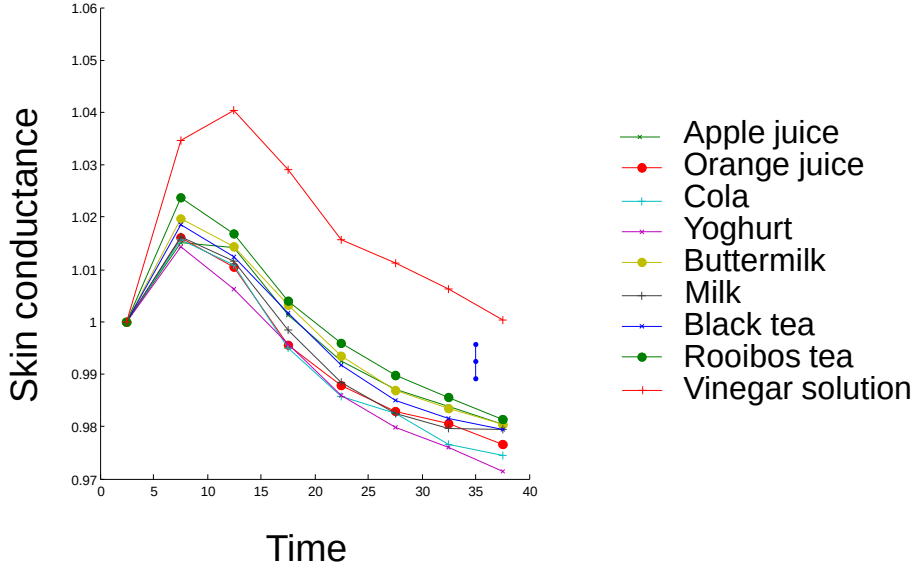
- Keep movements the same

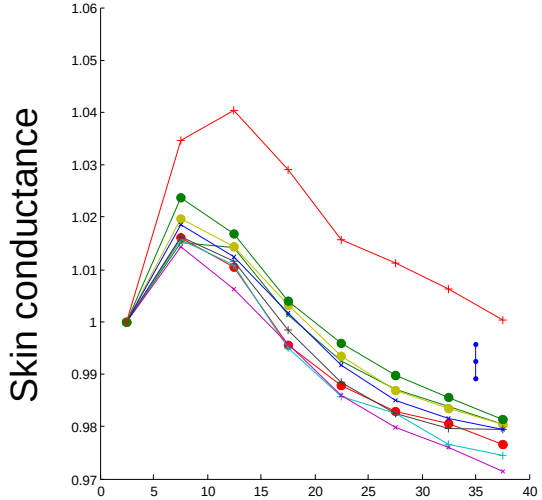
TOOLBOX TO MONITOR TASTE EXPERIENCE

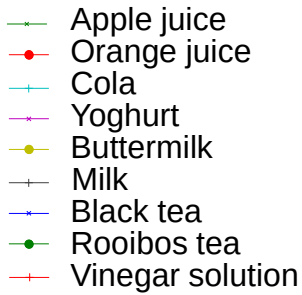
How strongly are different measures associated with taste experience?

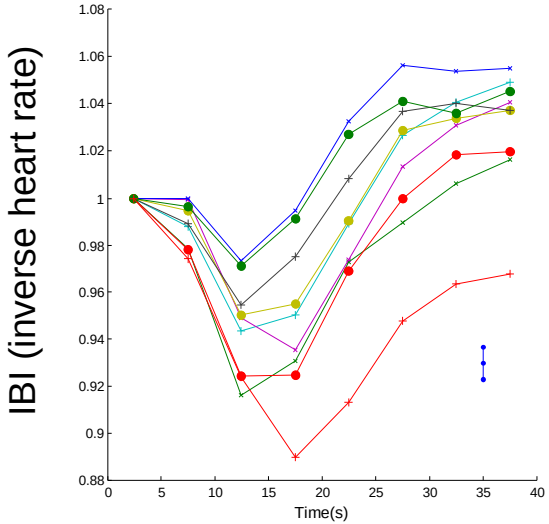
- 69 participants tasted different drinks
- ‘Ground truth’ negative, arousing food experience: diluted vinegar
- Subjective, physiological and behavioral measures

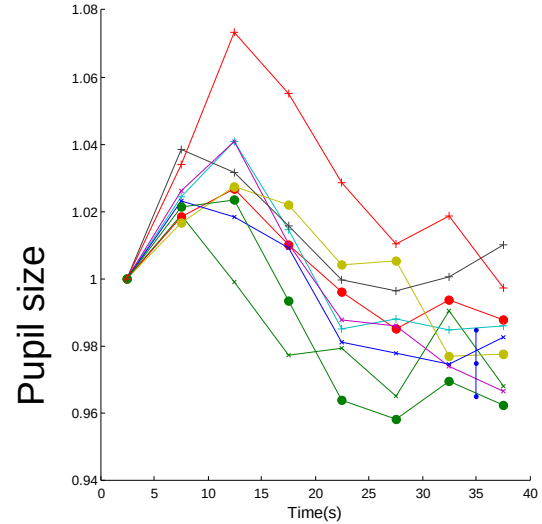


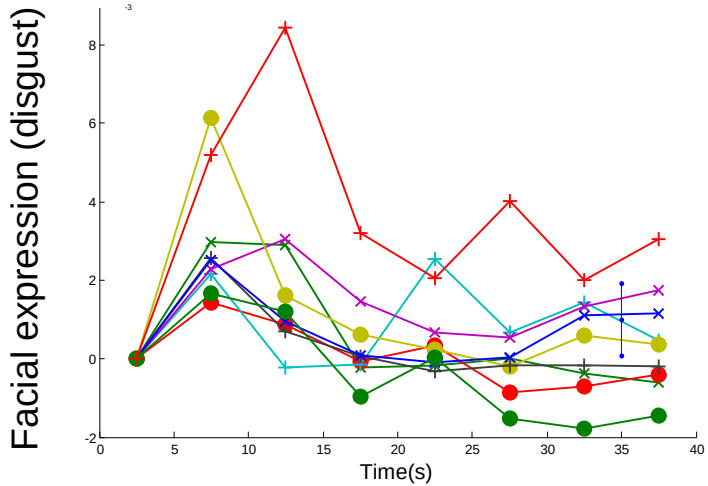

Skin conductance
1.06
1.05
1.04
1.03
1.02
1.01
1
0.99
0.98
0.97
0
5
10
15
20
25
30
35
40
Time
Apple juice
Orange juice
Cola
Yoghurt
Buttermilk
Milk
Black tea
Rooibos tea
Vinegar solution


Skin conductance
1.06
1.05
1.04
1.03
1.02
1.01
1
0.99
0.98
0.97
0
5
10
15
20
25
30
35
40


Apple juice
Orange juice
Cola
Yoghurt
Buttermilk
Milk
Black tea
Rooibos tea
Vinegar solution


IBI (inverse heart rate)
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
0.88
0
5
10
15
20
25
30
35
40
Time(s)


Pupil size
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0
5
10
15
20
25
30
35
40
Time(s)


Facial expression (disgust)
-3
8
6
4
2
0
-2
0
5
10
15
20
25
30
35
40
Time(s)

DISTINGUISHING VINEGAR FROM REGULAR DRINKS

	Z-score
Sip size	19.50
Valence score	14.84
Arousal score	13.42
IBI	10.99
Skin conductance	7.97
Disgust facial expression	5.97
Pupil size	4.33
Heart rate variability	1.94
Alpha asym F3F4	1.61

REGULAR DRINKS

	Valence		Arousal	
	rho	*p*-value	*rho*	*p*-value
Sip size	0.2290	0.5854	-0.3051	0.4624
IBI	-0.7326	0.0387	-0.9225	0.0011
Skin conductance	-0.3488	0.3972	-0.3718	0.3645
Pupil size	0.0189	0.9645	0.2210	0.5989
Heart rate variability	-0.6413	0.0866	-0.7093	0.0488
Alpha asym F3F4	0.8418	0.0088	0.6170	0.1032
Disgust face	-0.2285	0.5863	-0.0720	0.8655

CONCLUSION

Our study provides an overview of:

- Basic effects of taking a sip on several physiological variables
- Comparative sensitivity of several physiological, subjective and behavioral measures to discriminate between a known unpleasant drink and regular drinks

Physiological variables can differentiate between drinks associated with different emotional experiences, even for relatively small differences (regular drinks).

Kaneko, van Erp, Hogervorst, Toet, Kallen, Brouwer (submitted) Physiological responses to tasting drinks associated with different tasting experiences.

2. BODY MOVEMENT CHALLENGE

Approaches to deal with this challenge

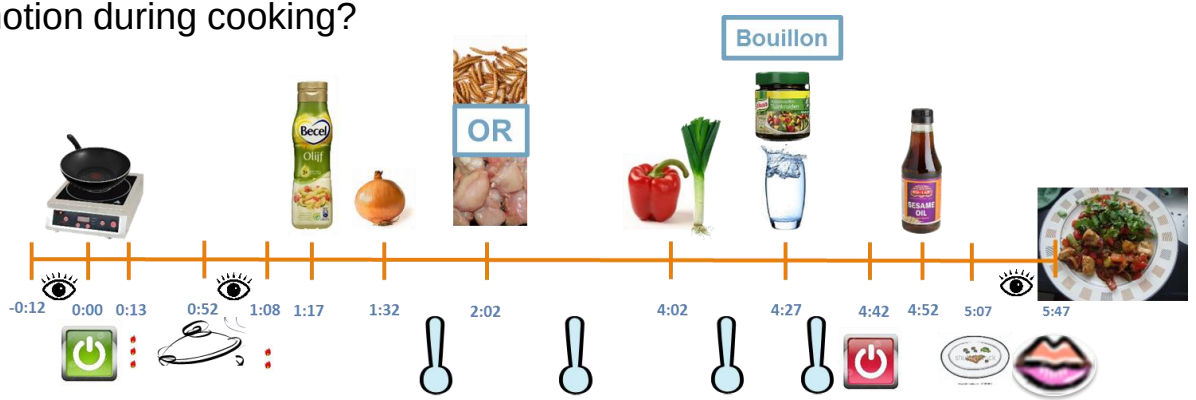
- Limit body movement
- Keep movements the same
- Correct for movement

CORRECT FOR MOVEMENTS: COOKING EXPERIENCE

- Food industry: need for implicit, continuous measure of experience in real life context
- Is it possible to estimating emotion during cooking?
- Chicken and mealworm

✓ Electrodermal variables and alpha asymmetry in expected direction

✓ 82% classification accuracy across participants



Brouwer, A.-M., Hogervorst, M.A., Grootjen, M., van Erp, J.B.F., Zandstra, E.H. (2017). Neurophysiological responses during cooking food associated with different emotions, Food Quality and Preference, 62, 307-316.

CORRECT FOR MOVEMENTS: COOKING EXPERIENCE

- What about more subtle differences in experience?
- Focus on differences in experience between cooking phases. Correcting for movement possible?

Additional heart rate: HR recorded = HR muscles + HR emotion

Blix, Stromme, Ursin (1974) Additional Heart Rate—An Indicator of Psychological Activation." Aerospace Medicine, 45 (11), 1219-1221.

- Myrtek: Estimate 'HR muscles' using accelerometers

Myrtek (2005) Heart and Emotion: Ambulatory Monitoring Studies in Everyday Life. Hogrefe & Huber

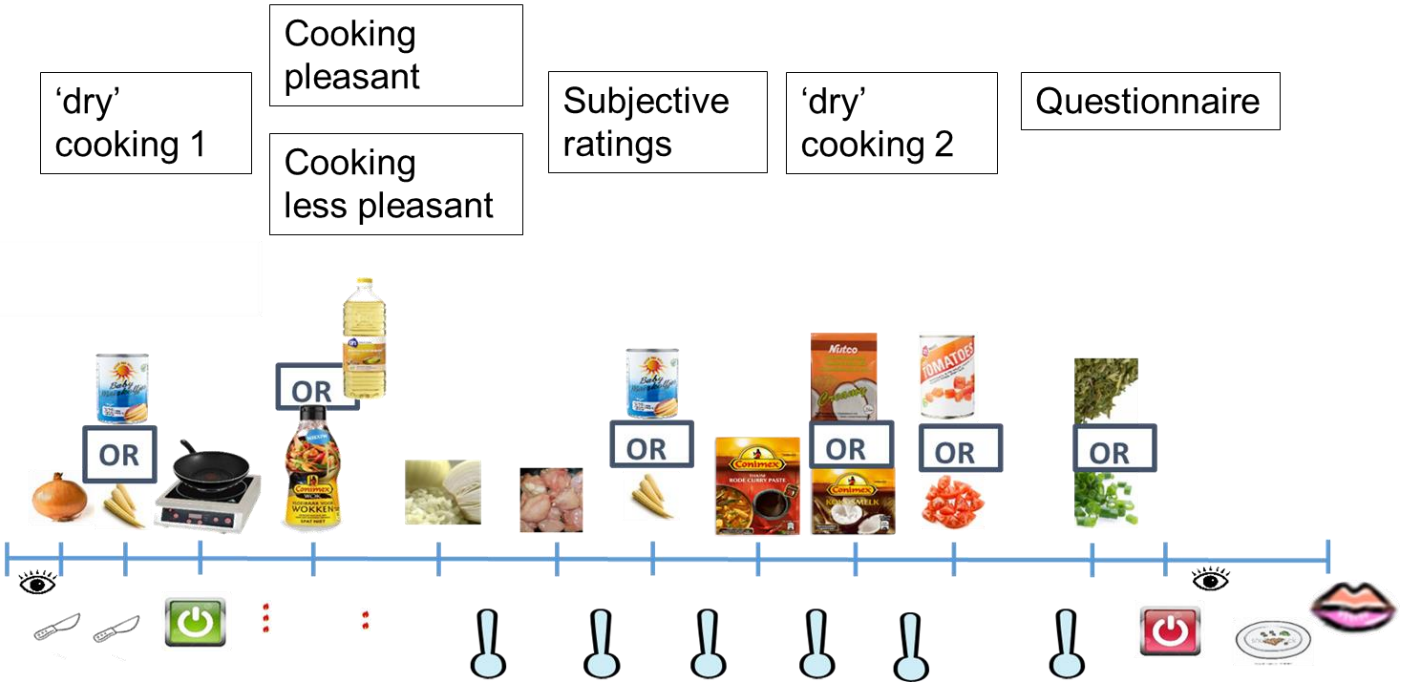
Motion indicated by accelerometers insufficient for capturing 'HR muscles'

- Use accelerometers to estimate type of activity, then use that to estimate energy expenditure (HR muscles?)

Bonomi, Plasqui, Goris, Westerterp (2009). Improving assessment of daily energy expenditure by identifying types of physical activity with a single accelerometer. J. Appl. Physiol. 107(3):655–661.

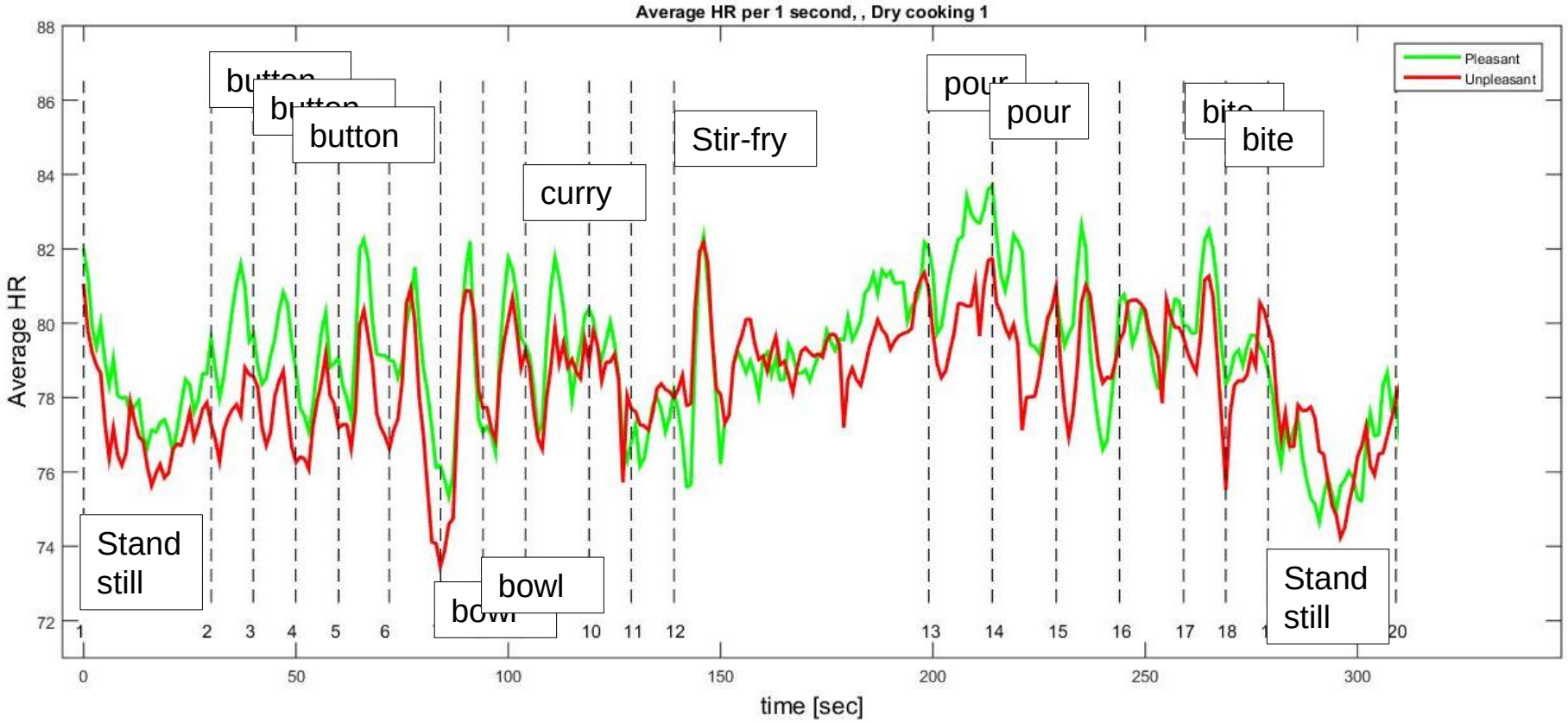
Altini, Penders, Vullers, Amft (2015) Estimating energy expenditure using body-worn accelerometers: a comparison of methods, sensors number and positioning. IEEE J Biomed Health Inform. 19(1):219-26.

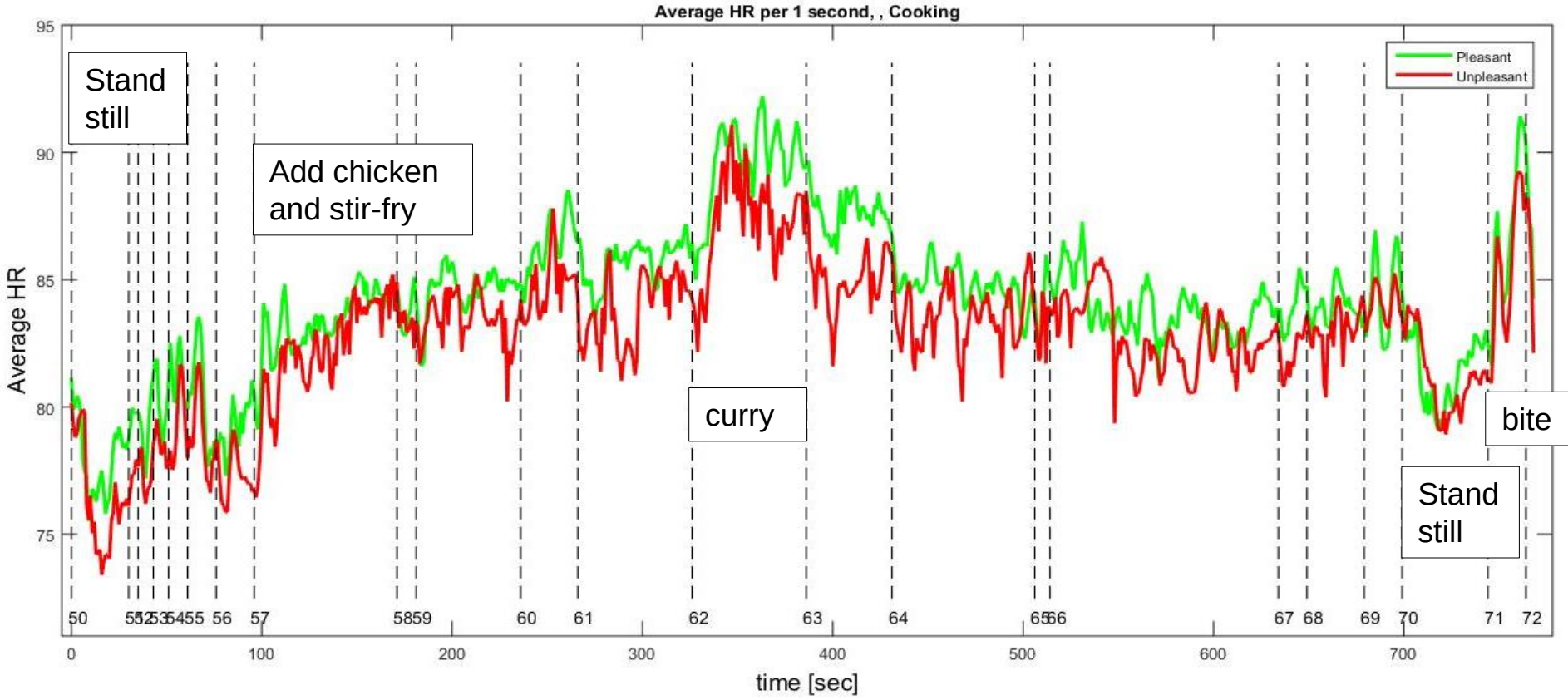
METHODS

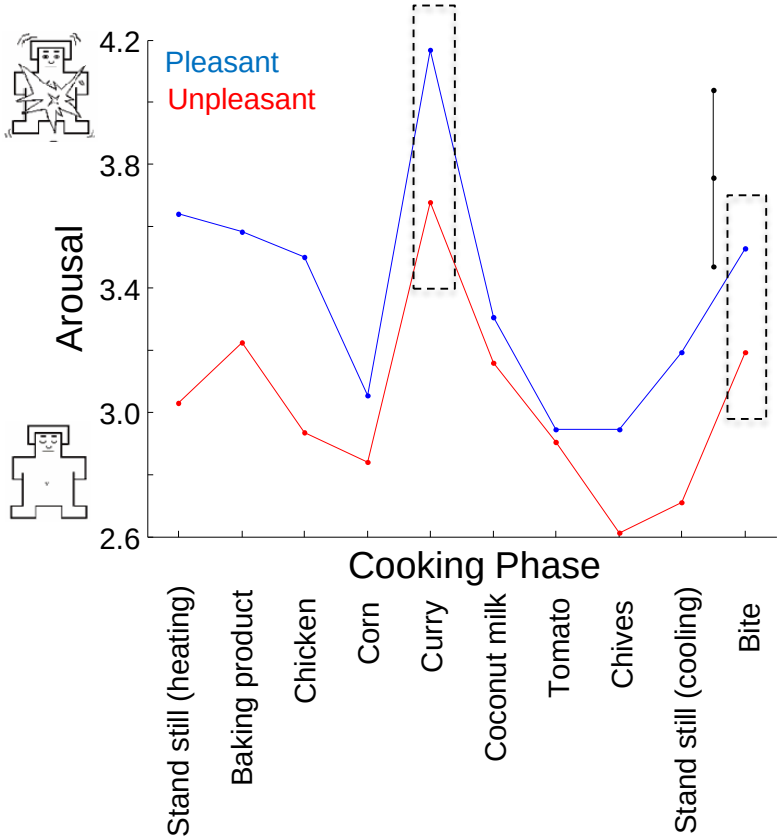

'dry' cooking 1
Cooking pleasant
Cooking less pleasant
Subjective ratings
'dry' cooking 2
Questionnaire
OR
OR
OR
OR
OR
OR
WOKKEN
Nutco
TOMATOES

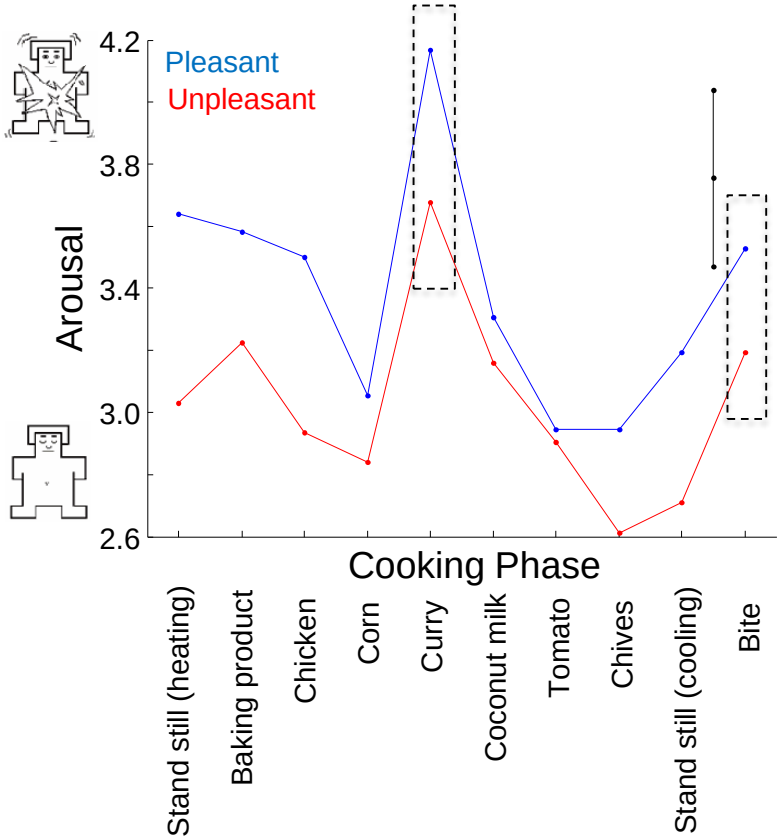
METHODS

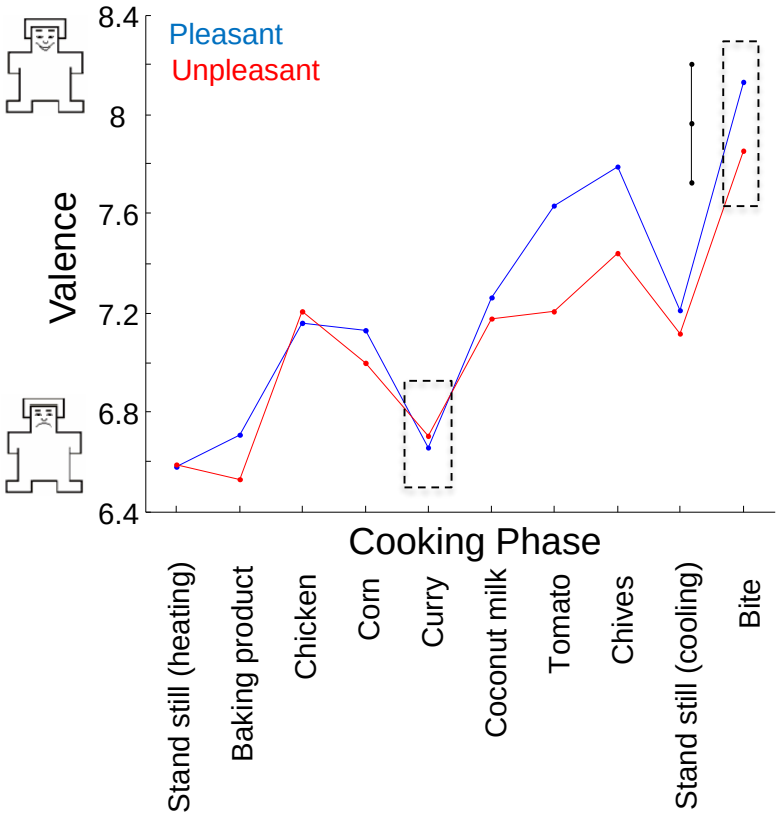
- 3 cameras (facial expression and validation)
- ECG and wearable
- Skin conductance
- EEG
- Three motion sensors: wrists and hip
- Subjective reports
- 74 participants


Average HR per 1 second, , Dry cooking 1
Pleasant
Unpleasant
Average HR
time [sec]
button
button
curry
Stir-fry
pour
pour
bite
bite
Stand still
bowl
bowl
Stand still


Average HR per 1 second, , Cooking
Pleasant
Unpleasant
Stand still
Add chicken and stir-fry
curry
bite
Stand still
Average HR
time [sec]
95
90
85
80
75
0
100
200
300
400
500
600
700
50
56
57
60
61
62
63
64
67
68
69
70
71
72


Pleasant
Unpleasant
Arousal
4.2
3.8
3.4
3.0
2.6
Cooking Phase
Stand still (heating)
Baking product
Chicken
Corn
Curry
Coconut milk
Tomato
Chives
Stand still (cooling)
Bite


Pleasant
Unpleasant
Arousal
4.2
3.8
3.4
3.0
2.6
Cooking Phase
Stand still (heating)
Baking product
Chicken
Corn
Curry
Coconut milk
Tomato
Chives
Stand still (cooling)
Bite

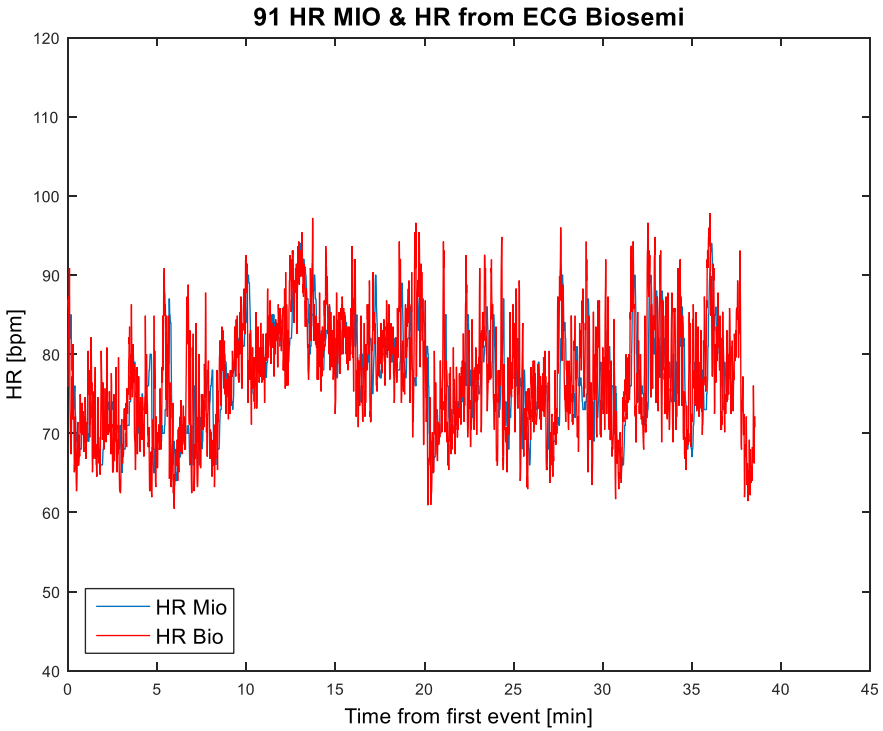

Pleasant
Unpleasant
Valence
8.4
8
7.6
7.2
6.8
6.4
Cooking Phase
Stand still (heating)
Baking product
Chicken
Corn
Curry
Coconut milk
Tomato
Chives
Stand still (cooling)
Bite

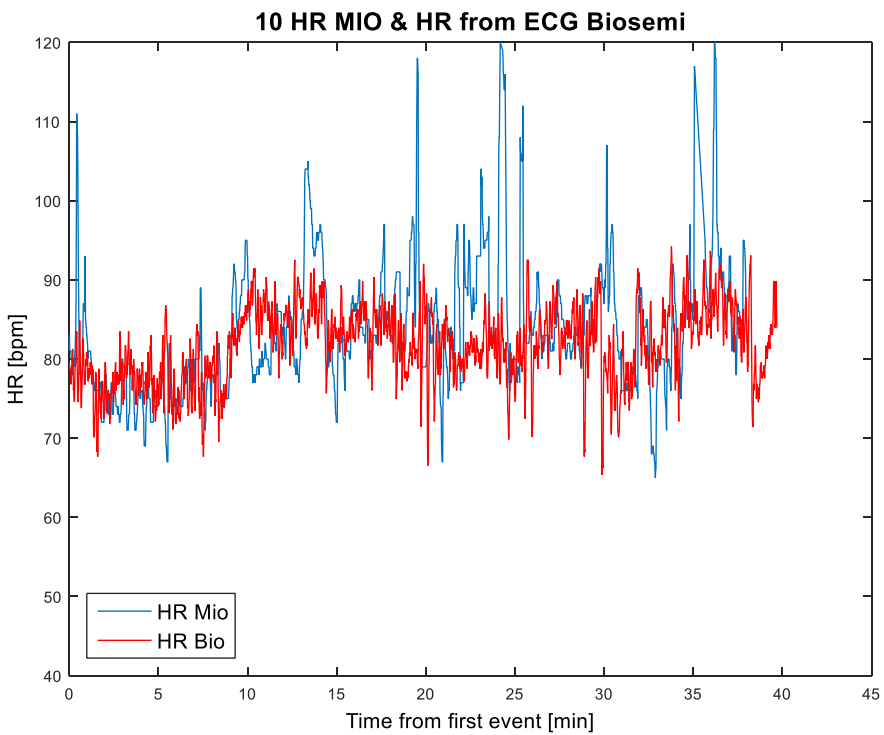
CONCLUSIONS

- Subtle differences between ingredients difficult to register between participants (subjective rating and physiology)
- Systematic effects of (subtle) movements on heart rate
- Identification of emotionally meaningful events during cooking may be possible using physiology

By the way..

HEART RATE: BIOSEMI ECG & MIO FUSE OPTIC





3. ADDED VALUE CHALLENGE

Does (adding) mental state monitoring result in better performance or well-being?

It helps when:

- Costs are low
  - no (individual) training data collection required
  - non-invasive sensors
- Information difficult to gain in other ways
  - specific reason to mistrust verbal reports
  - mental state needs to be estimated continuously

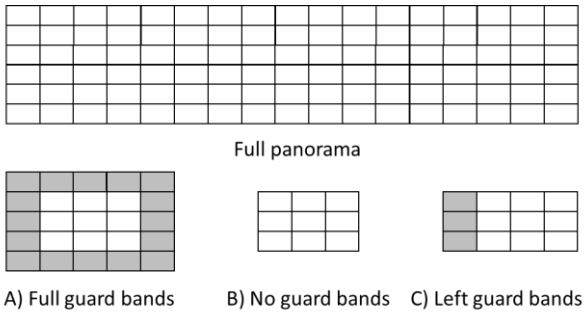
PREDICTING HEAD ROTATION FOR IMPROVING VR STREAMING

Solution for problems of conflicting requirements delay-spatial resolution in HMD imaging over networks:

- Have guard bands available locally

More optimal choice between spending bandwidth on better resolution or lower delay would be possible if we have information on whether/when/where the head is going to rotate.

Brain signals as a solution?



GOOD APPLICATION AREA FOR ADDED VALUE

- No obvious alternative source of information
- Collecting correctly labelled data to train the model on the fly
- Continuous monitoring of own performance is possible
- ‘Only’ improving an already working system
- ..based on information that does not need to be 100% accurate
- Electrodes potentially fit with HMD

PREVIOUS WORK

- Distinct types of EEG activity precedes body movements

(Contingent negative variation: Walter et al., 1964; Readiness potential: Kornhuber & Deecke, 1965; Lateralized readiness potential: Coles, 1989; Lateralized event related desynchronization: Pfurtscheller, 2001)

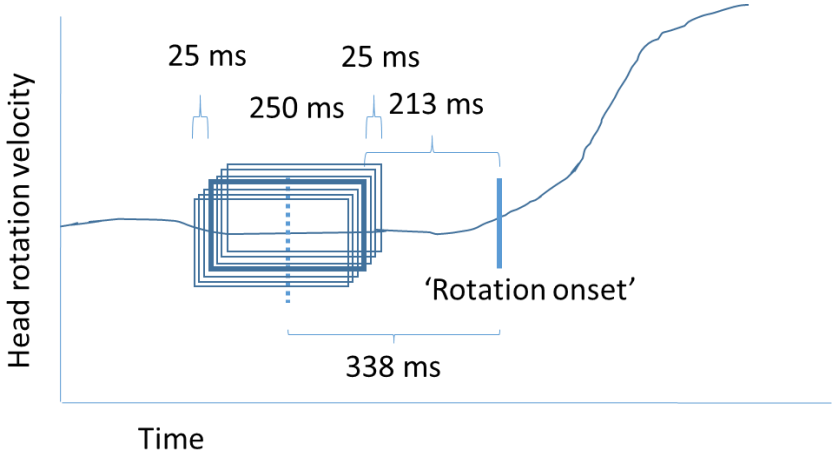
- Single trial prediction of body movement (arm, leg) has been shown

(Lew et al. (2012): self-paced reaching; Gheorge et al. (2013): steering wheel; Haufe et al (2014): emergency braking in real driving)

What about head rotation?

METHODS

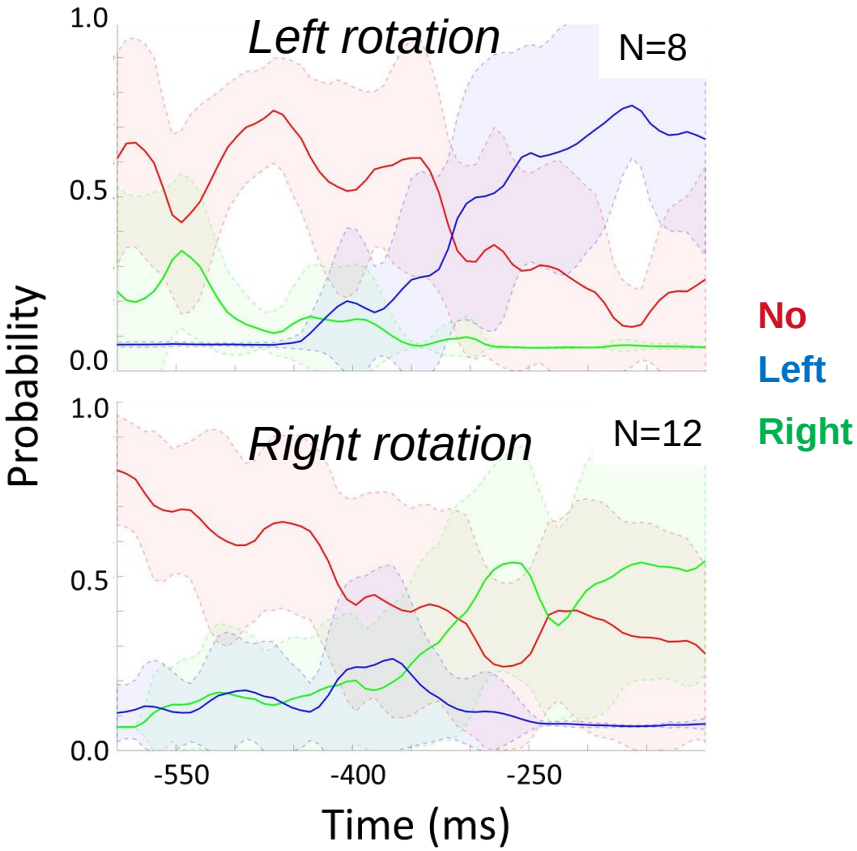
- Participant makes self-initiated rotations to the left or right, two times 20 minutes
- EEG and motions sensors from HMD
- Multi-layer perceptron trained to distinguish intervals preceding no, left, right movement



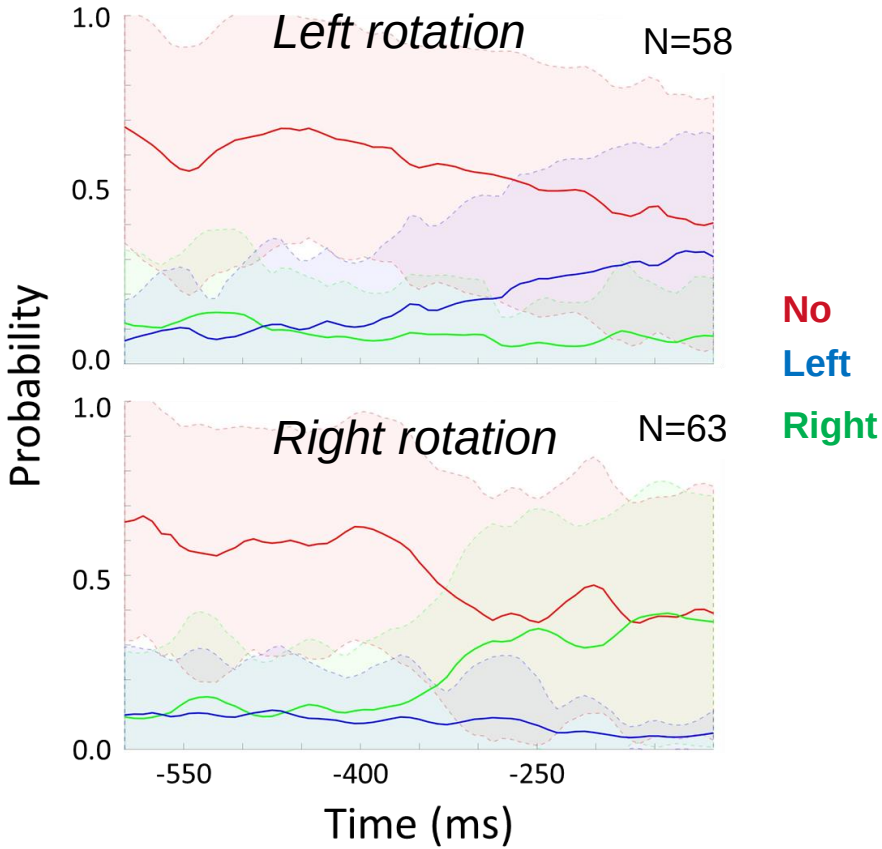
RESULTS

Classification on 4 minutes of streaming data: every 7.8 ms new 250 ms window of EEG data

‘Prediction in real time’



RESULTS


Left rotation
N=58
Right rotation
N=63
1.0
0.5
0.0
Probability
-550
-400
-250
Time (ms)
No
Left
Right

CONCLUSION

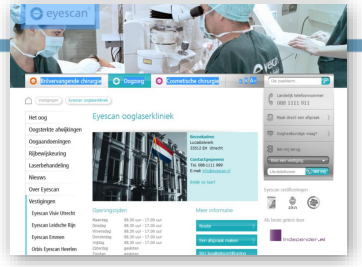
- We found that whether, and in which direction a head is going to rotate can be predicted on the basis of EEG starting at around 400 ms before the rotation occurs.
- Ample time for adapting VR streaming

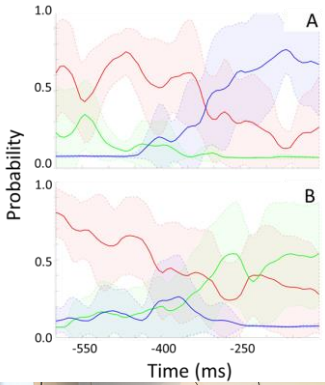
Brouwer, van der Waa, Hogervorst, Cacace, Stokking. (2017). A Feasible BCI in Real Life: Using Predicted Head Rotation to Improve HMD Imaging. Proceedings of the 2017 ACM Workshop on An Application-oriented Approach to BCI out of the laboratory, 35-38.

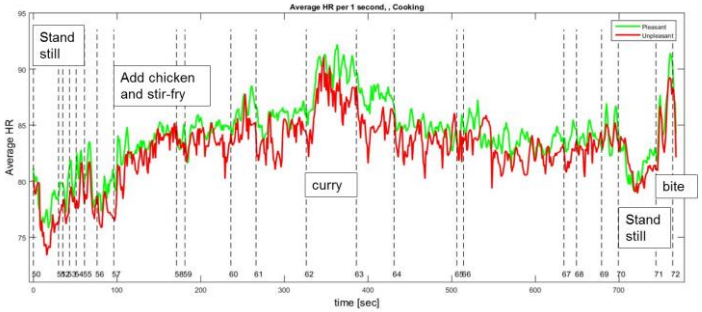
Brouwer, van der Waa, Stokking. (submitted). EEG assisted VR streaming: reducing delays by predicting head rotation

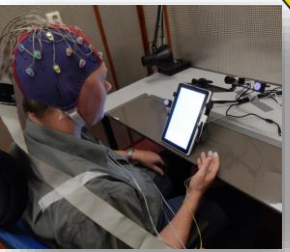
CHALLENGES

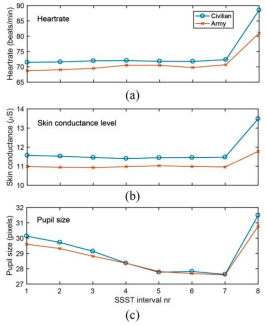
1. No simple mapping between physic
2. Effects of body movement on physi
3. How can our (imperfect) estimates

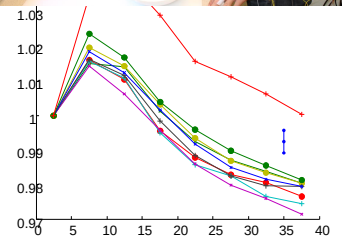












RESEARCH TEAMS

Head rotation

Jasper van der Waa

Hans Stokking

Cooking

Christa Gjaltema
Maarten Hogervorst
Wieke Oldenhof
Martin van Schaik
Jan Ubbo van Baardewijk
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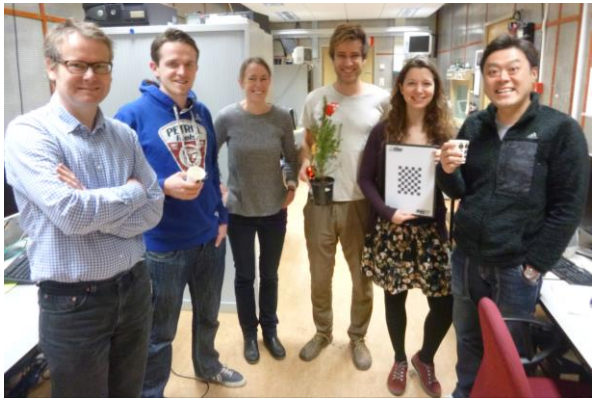
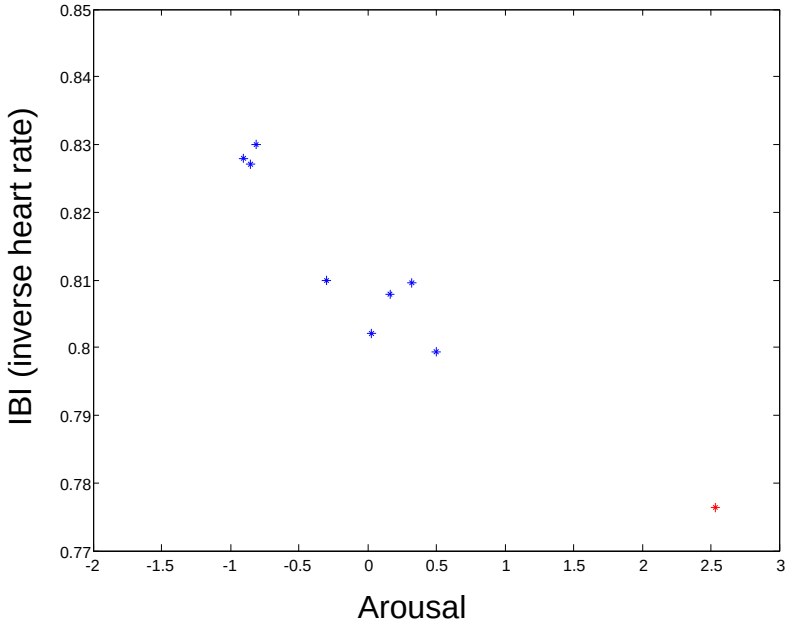
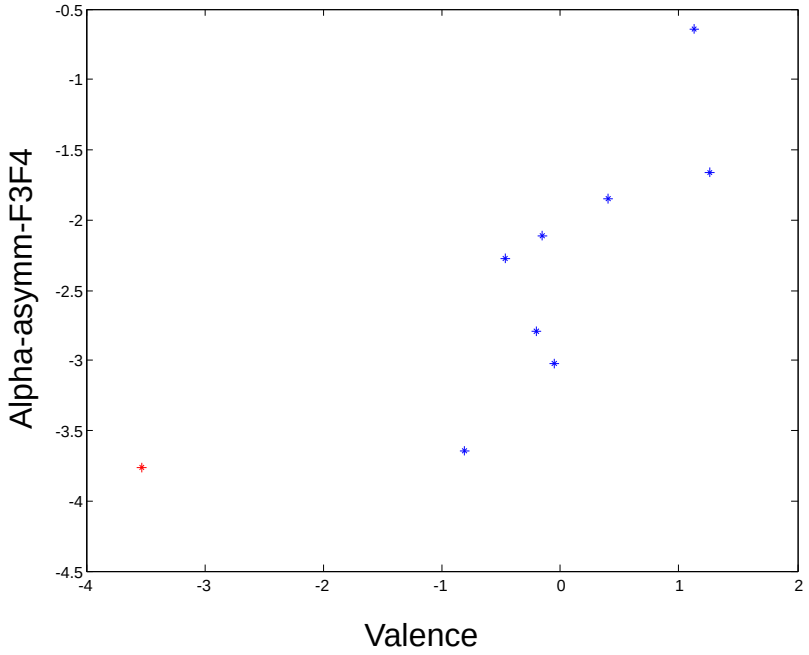
Jan van Erp
Liesbeth Zandstra (Unilever)
Pim Nijdam (Eaglescience)
Elsbeth van Dam (Noldus)

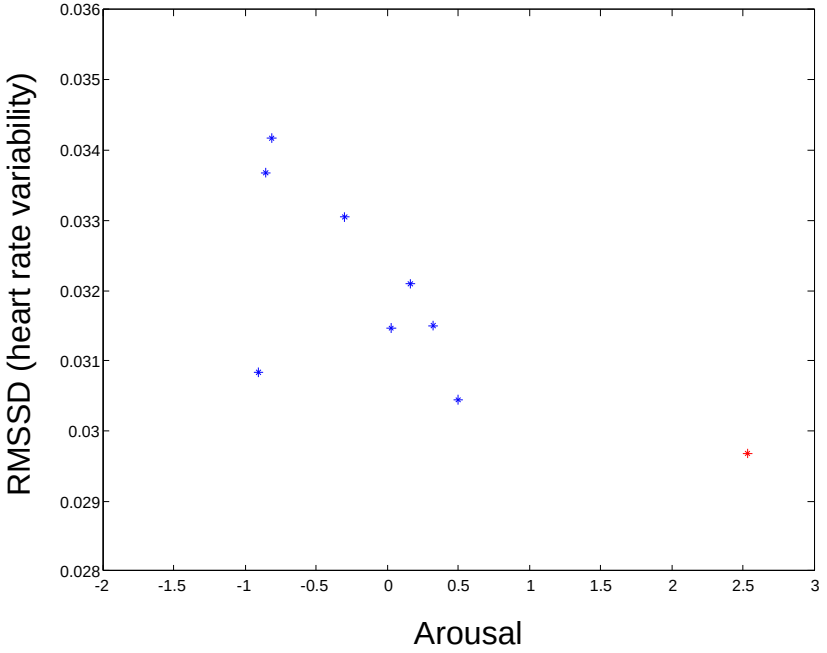
Tasting

Daisuke Kaneko (Kikkoman)
Maarten Hogervorst
Esther Bosch
Wouter Korteling
Benjamin de Graaff
Lex Toet
Victor Kallen
Jan van Erp




IBI (inverse heart rate)
0.85
0.84
0.83
0.82
0.81
0.8
0.79
0.78
0.77
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3
Arousal


Alpha-asymm-F3F4
Valence
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-4
-3
-2
-1
0
1
2


RMSSD (heart rate variability)
Arousal
0.036
0.035
0.034
0.033
0.032
0.031
0.03
0.029
0.028
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3