Universiteit Leiden
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HOW EFFORTFUL IS COGNITIVE CONTROL?

EVIDENCE FROM PUPILLOMETRY, FACIAL EMG, AND A NOVEL CARDIOVASCULAR MEASURE

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How does effort relate to cognitive control?

"[…] cognitive effort regulates the degree to which cognitive control is engaged […]" (Shenhav et al., 2017)

Annu. Rev. Neurosci. 2017. 40:99–124

Toward a Rational and Mechanistic Account of Mental Effort

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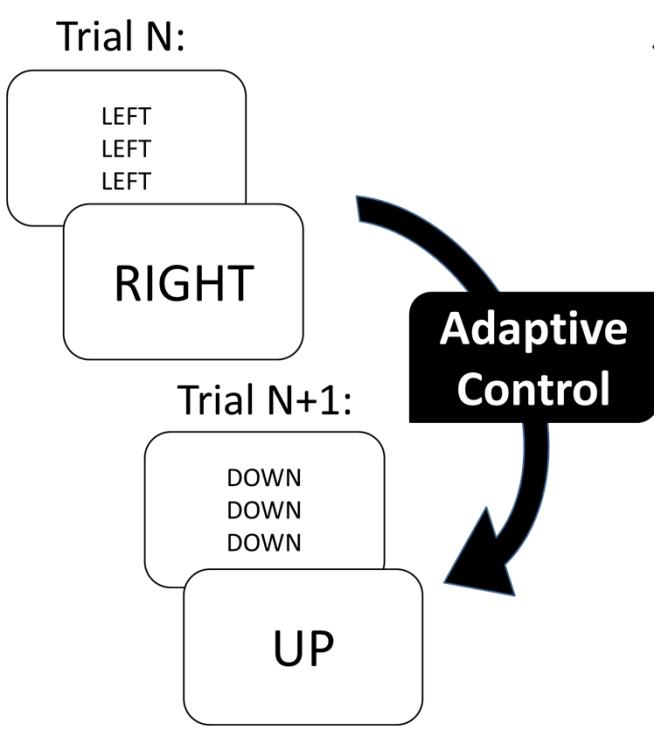
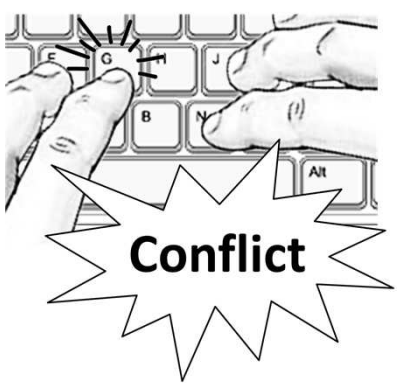
Wouter Kool,[5] Thomas L. Griffiths,[6]
Jonathan D. Cohen,[3,7] and Matthew M. Botvinick[8,9]

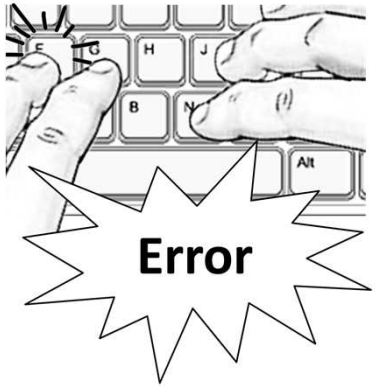
Physiological indicators of effort?

1. Pupil dilation
2. Facial EMG of frowning muscle
3. New cardiovascular measure of effort

Demand-driven adjustments in cognitive control







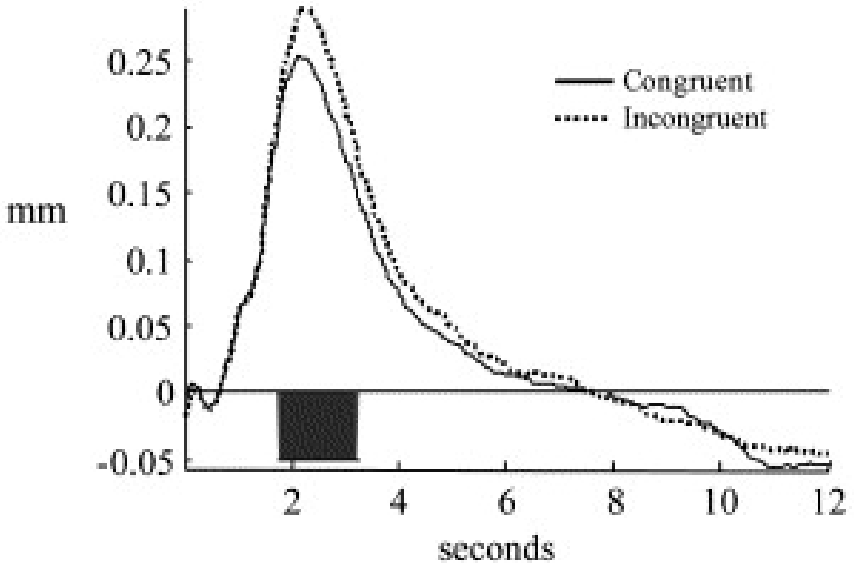
Focusing

Slowing

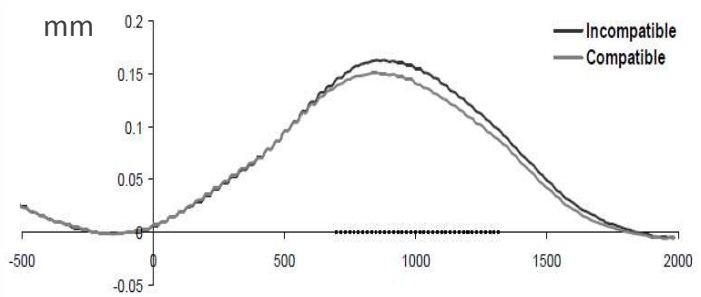
See Schmidt, J. R., & Weissman, D. D. H. (2014). Congruency sequence effects without feature integration or contingency learning confounds. *PloS ONE*, 9(7), e102337.

Pupil dilation in conflict tasks

Siegle et al. 2004

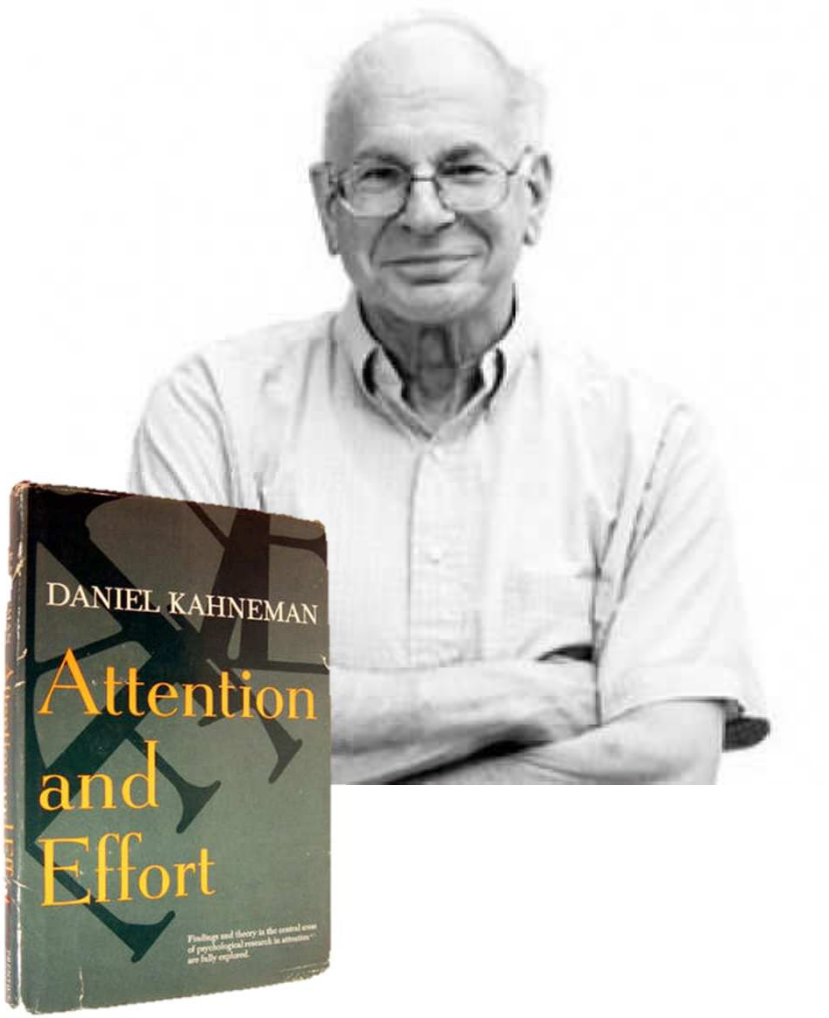


van Steenbergen & Band, 2013



time (ms)

Pupil dilation:
Task demands or effort allocation?

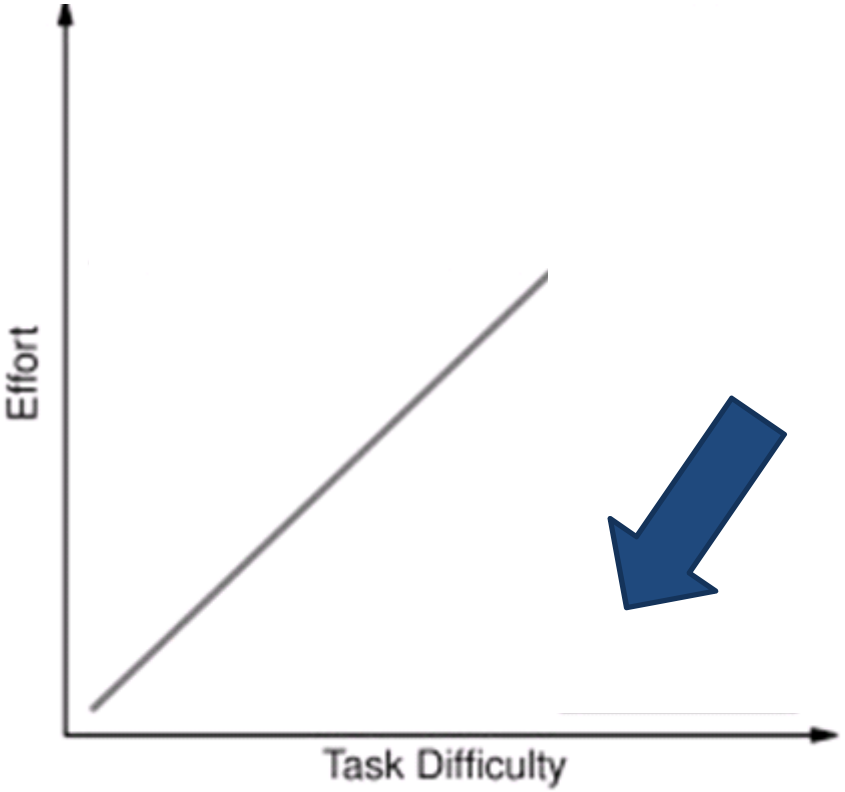


- "The fundamental difficulty in the use of physiological techniques to measure effort is caused by the similarity between the physiological response to *mental effort* and to *stress*"

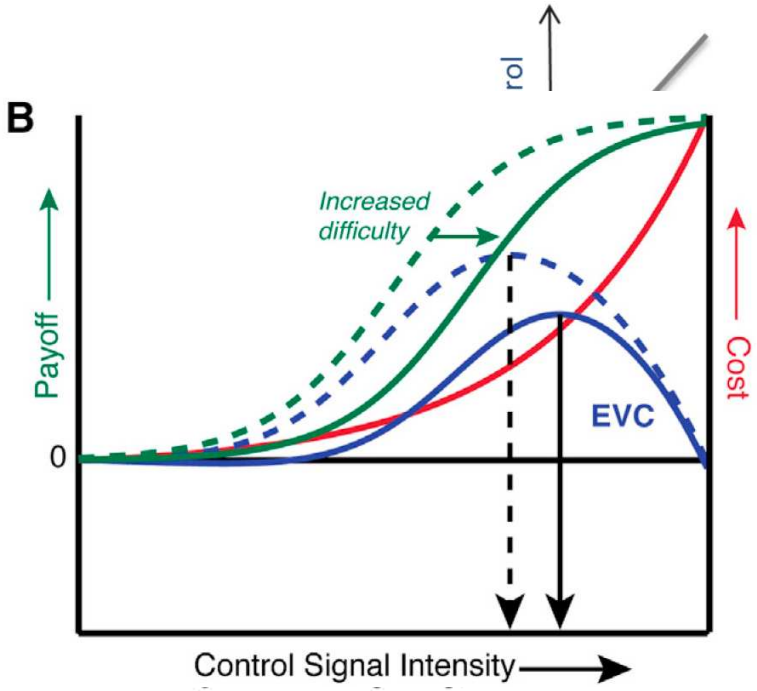
Kahneman (1973), p.17

44 years later… What have we learned?

- Task **demand** (need for effort) vs. actual **effort** exerted
- Problem: **demands** and **effort** typically co-vary
- Solution: investigate range where they are dissociated

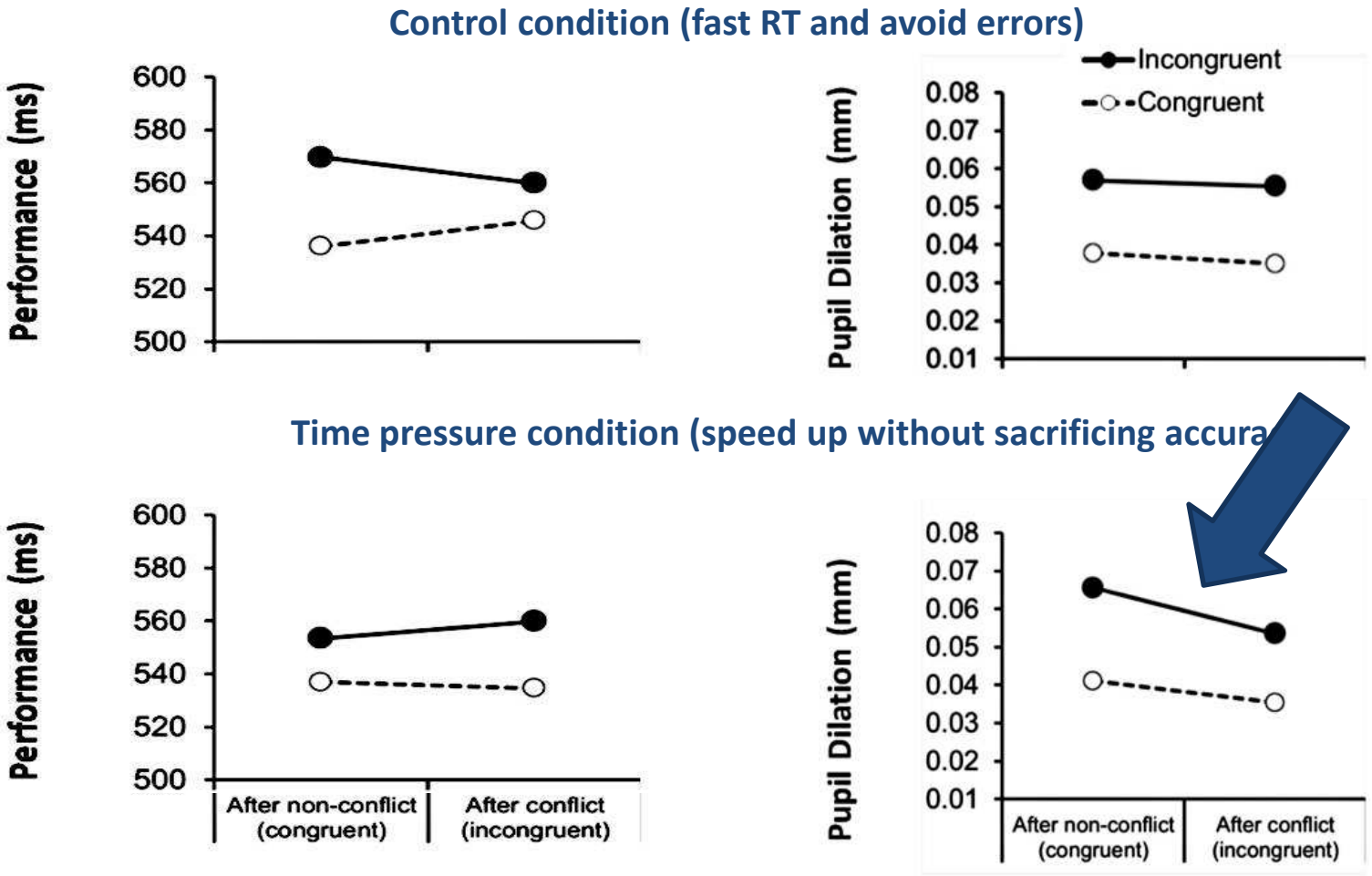


Motivation Intensity Theory (Brehm & Self, 1989)



Expected Value of Control Theory (Botvinick et al., 2001, 2013)

Time pressure manipulation reduces conflict adaptation AND post-conflict pupil dilation



van Steenbergen, H., Band, G.P.H., & Hommel, B. (2015). Does conflict help or hurt cognitive control? Initial evidence for an inverted U-shape relationship between perceived task difficulty and conflict adaptation. *Frontiers in Psychology*, 6:974.

Pupil dilation in cognitive control tasks

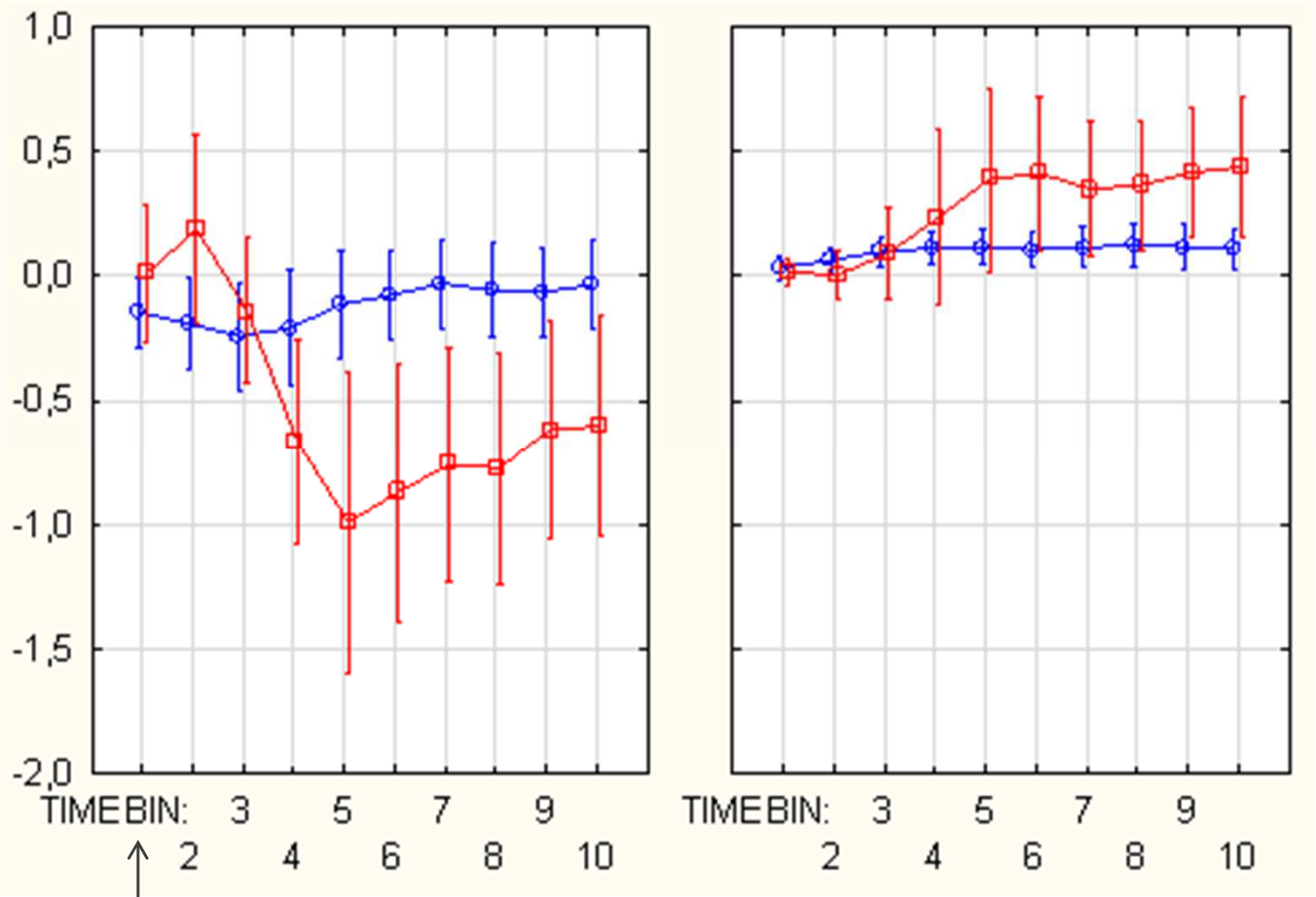
- In conditions of extreme demands: effort should be reduced.
- Pupil dilation consistent with this prediction
- Pupil dilation correlates with performance

- Most parsimonious explanation of available data: pupil dilation can be used as an index of effort

van der Wel, P. & van Steenbergen, H. (in revision). Pupil dilation as an index of effort in cognitive control tasks: A review. *Psychonomic Bulletin & Review*

Errors and facial EMG

Corrugator (frown) Zygomaticus (smile)



--- **Error**
--- **Correct**

Error bars show 95%CI

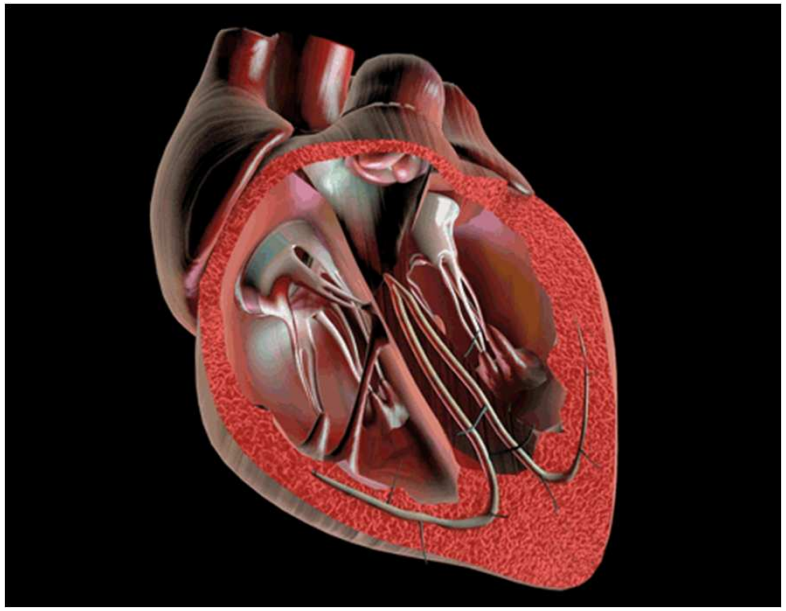
Timebins of 100 ms

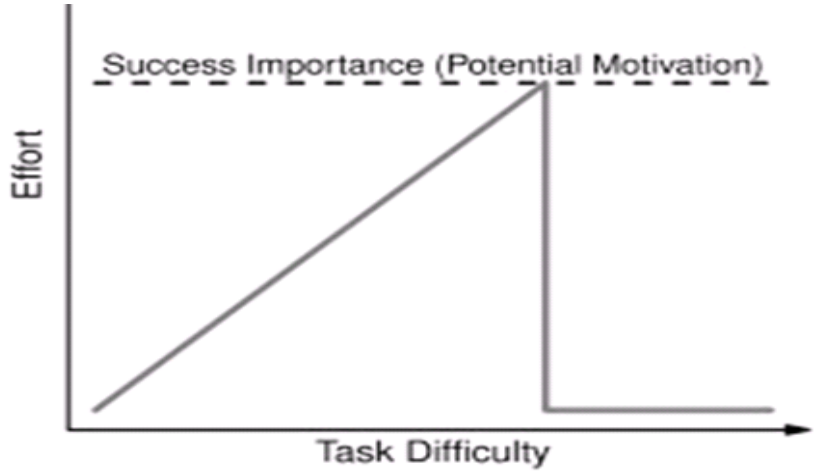
Time 0 = Response onset

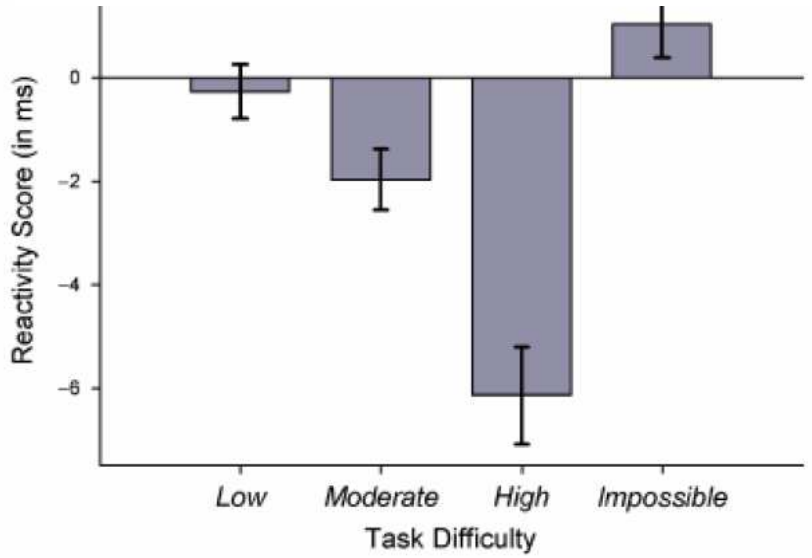
Berger, A. & van Steenbergen, H. (in preparation)

Cardiac contractility:
A more specific index of effort?

Force of myocardial contraction
reflected in the pre-ejection period (PEP)

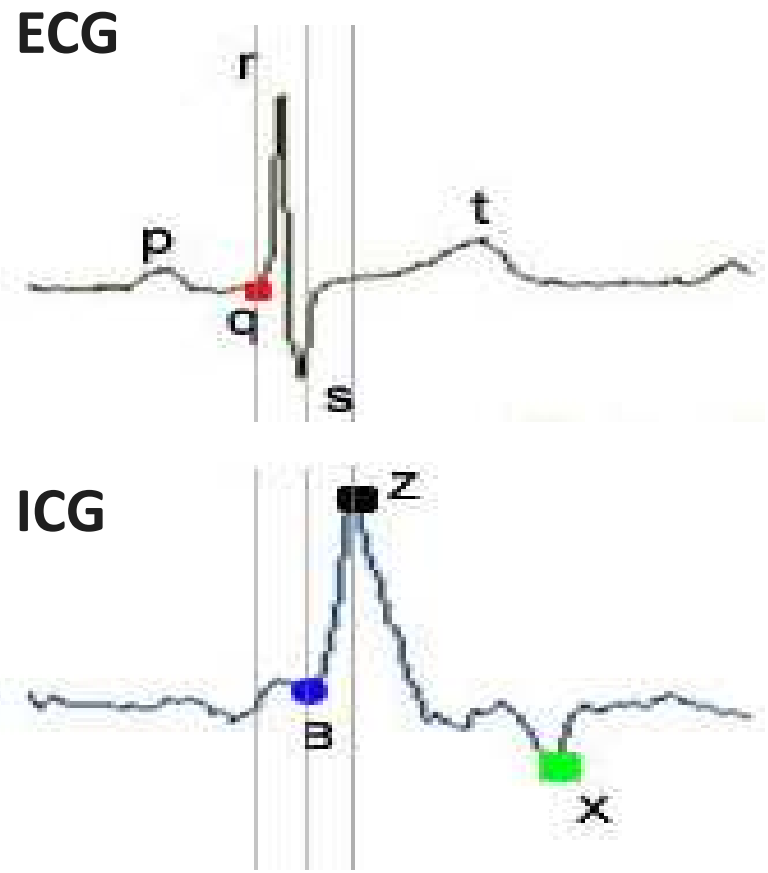






Richter, M., Friedrich, A., & Gendolla, G. H. (2008). Task difficulty effects on cardiac activity.*Psychophysiology*, *45*(5), 869-875.

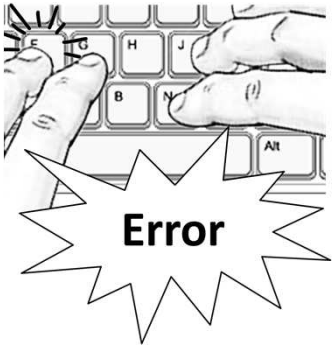
New method: RZ interval as a proxy of PEP



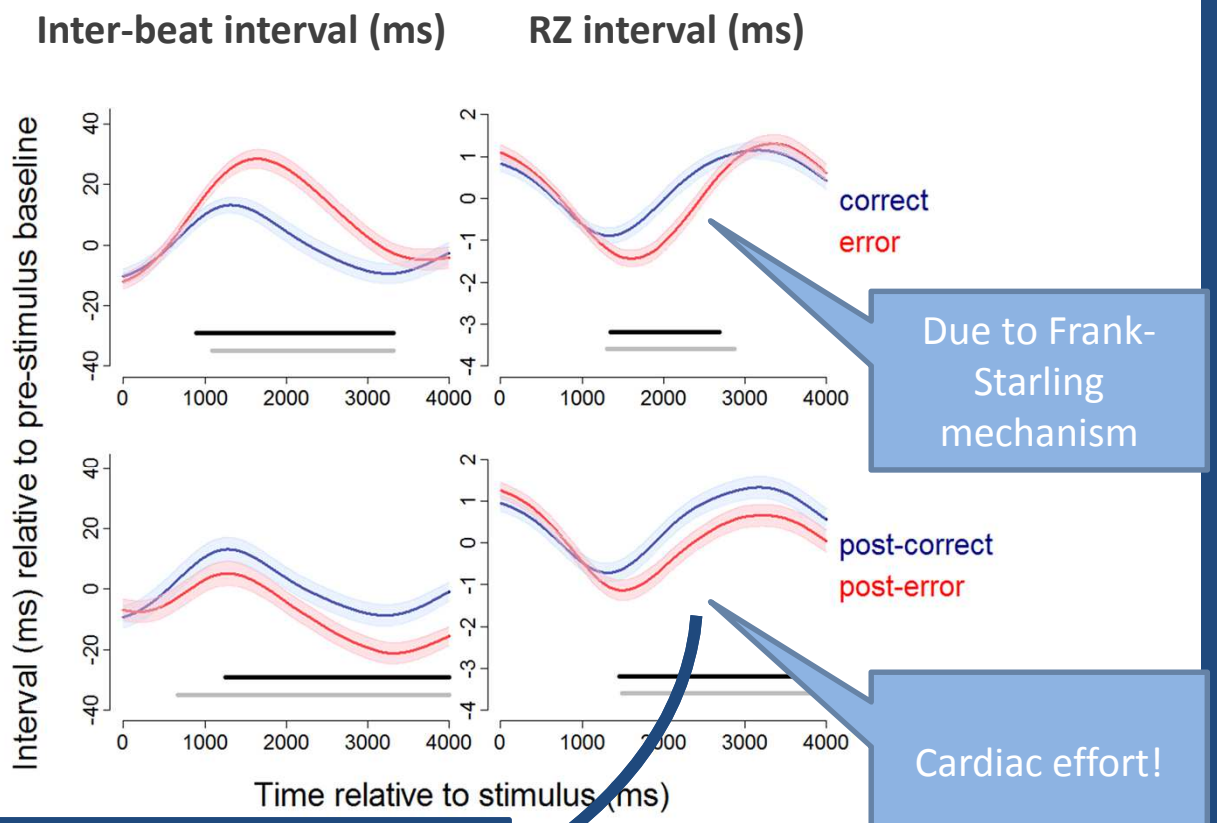
- Traditional PEP based on ensemble-averaged data: qB interval
- Single-trial analyses: proxy of PEP:
  RZ interval
  (cf. Lozano et al. 2007)

Kuipers, M., Richter, M., Scheepers, D., Immink, M., Sjak-Shie, E., & van Steenbergen, H. (2017). How effortful is cognitive control? Insights from a novel method measuring single-trial evoked beta-adrenergic cardiac reactivity. *International Journal of Psychophysiology*

Post-error adaptations involve cardiac effort



Slowing



Due to Frank-Starling mechanism

Cardiac effort!

Multilevel analyses:
RZI decrease (effort) predicts post-error slowing

Spruit, I.M., Wilderjans, T.M., & van Steenbergen, H. (accepted pending minor revisions). Heart work after errors: Behavioral adjustment following error commission involves cardiac effort. *Cognitive, Affective & Behavioral Neuroscience*

Conclusions

- Effort is an important aspect of cognitive control

- Pupil dilation: useful index of effort
- Frowning muscle: might reflect effort but EMG data is noisy
- Cardiovascular RZI: promising new method to investigate effort

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