The cost function during human motor control

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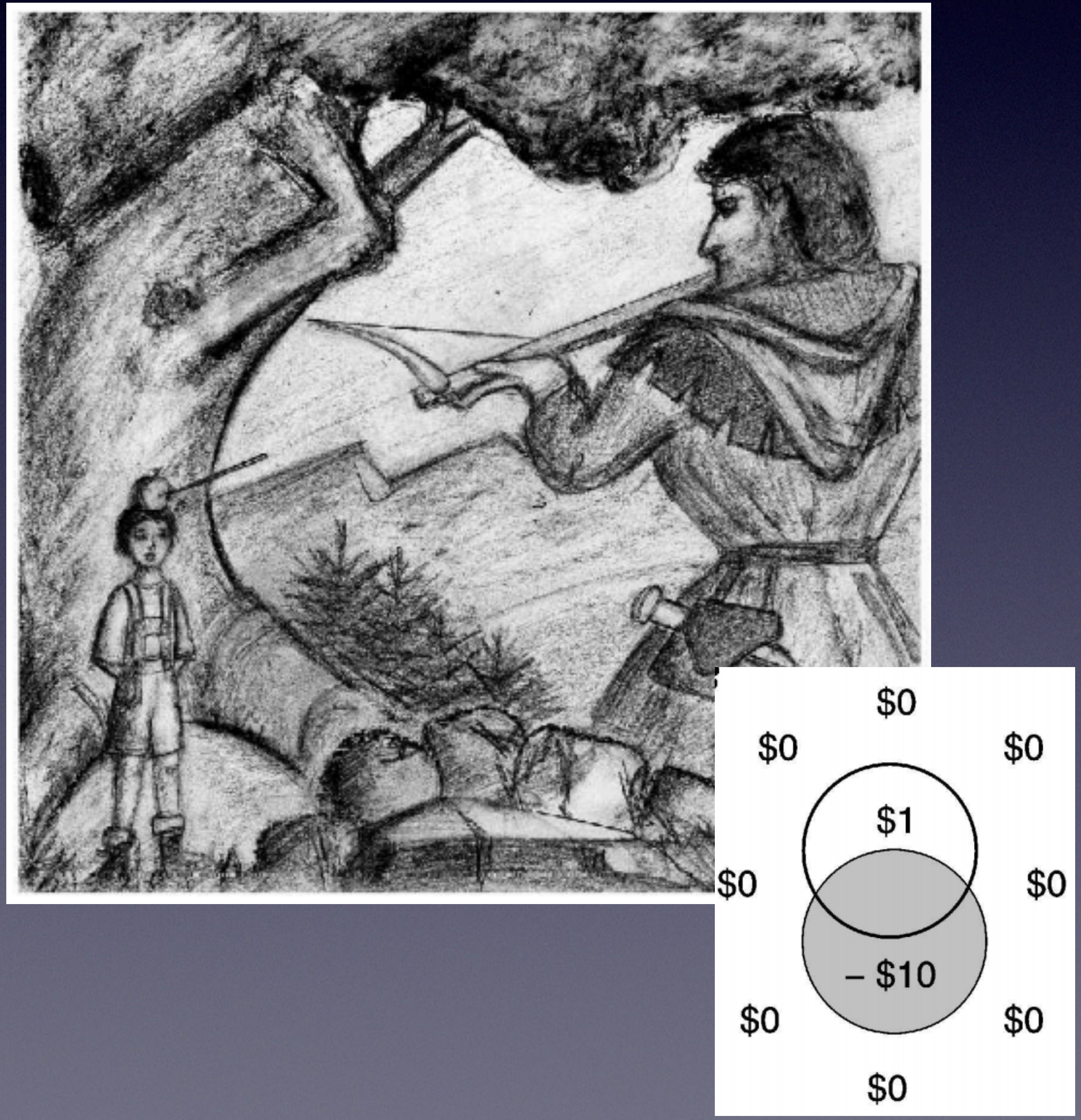
The cost function in motor control

- View movement planning and control as a problem of statistical decision theory
- The choice of a movement plan depends on the consequence of the movement, which specified by a cost function (e.g., Effort, Error, Uncertainty).
- **Question: Can humans objectively represent these measures?**



Trommershäuser J, Maloney LT, Landy MS, 2003

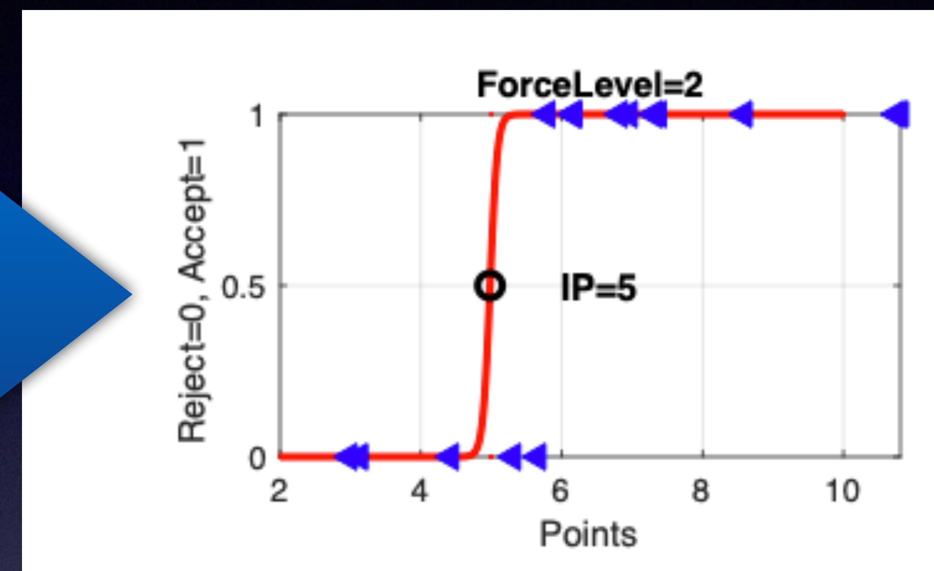
Abstract

- Three examples of costs and their subjective utility: Effort, Error, and Uncertainty/Risk.
- Although persistent findings of human being ‘suboptimal’, the use of an optimality approach might still be the best bet to understand human motor control.

Example 1: Effort perception

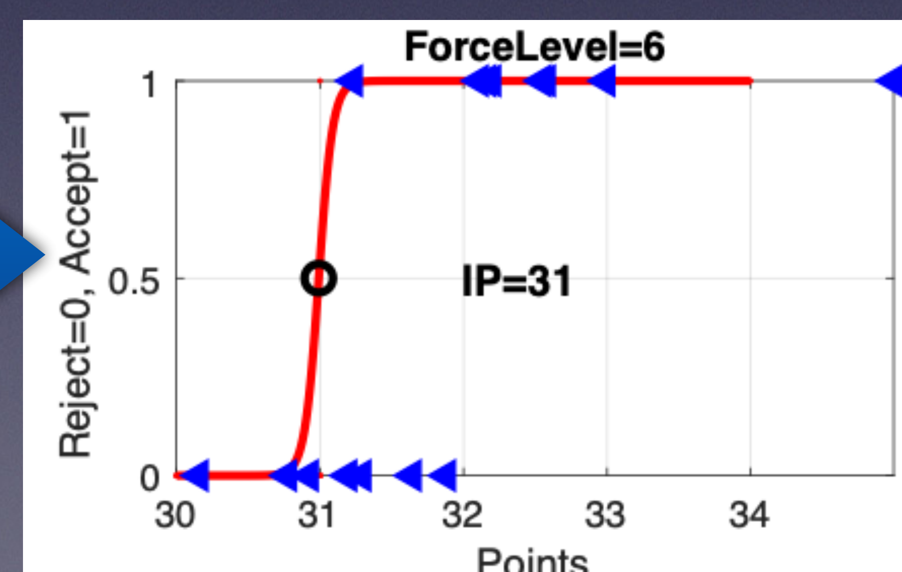
YES 15 points

NO 0 points



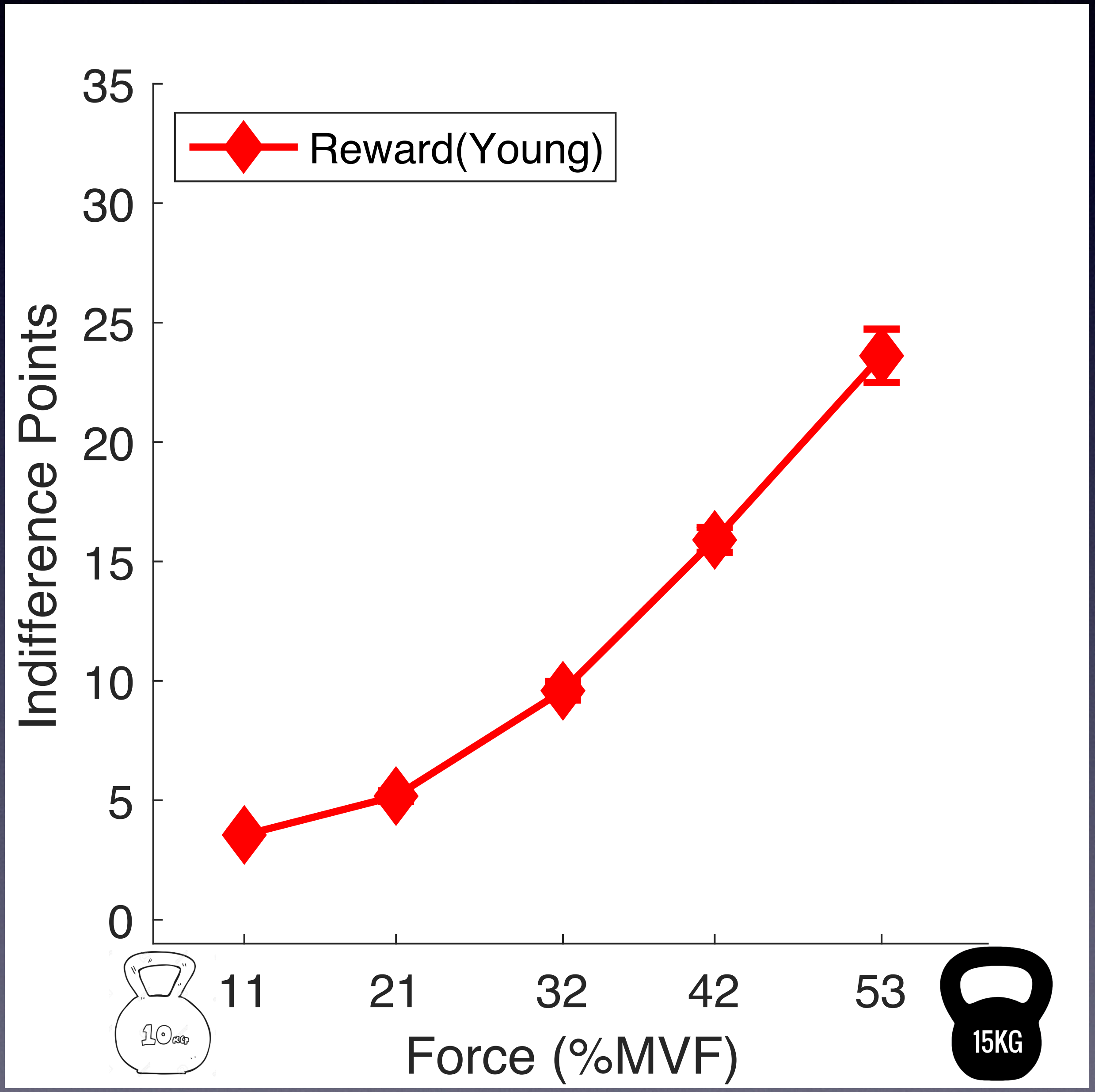
YES 20 points

NO 0 points



Chen et al., (in preparation)

Example 1: Effort perception

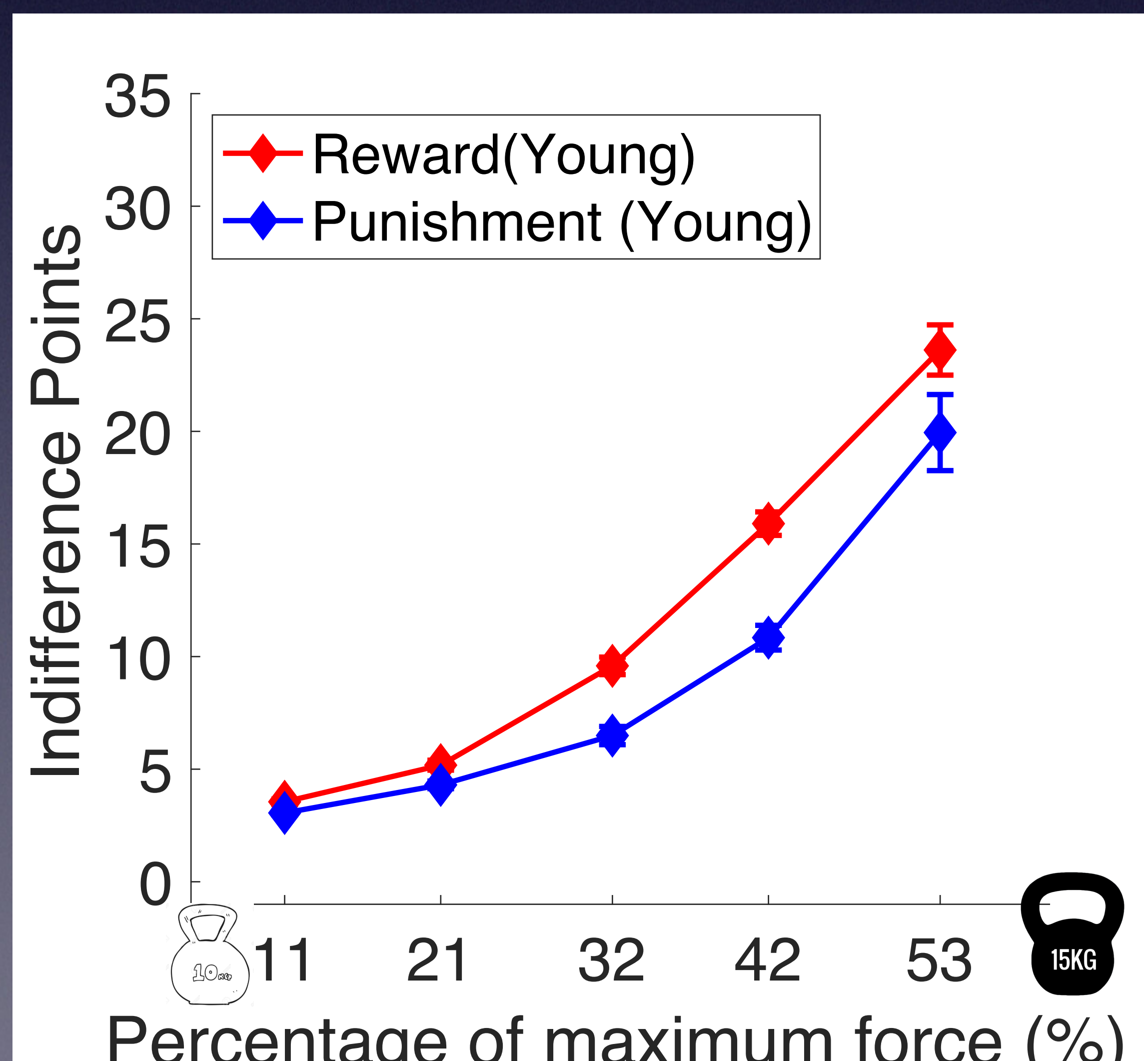


Chen et al., (in preparation)

Example 1: Effort perception

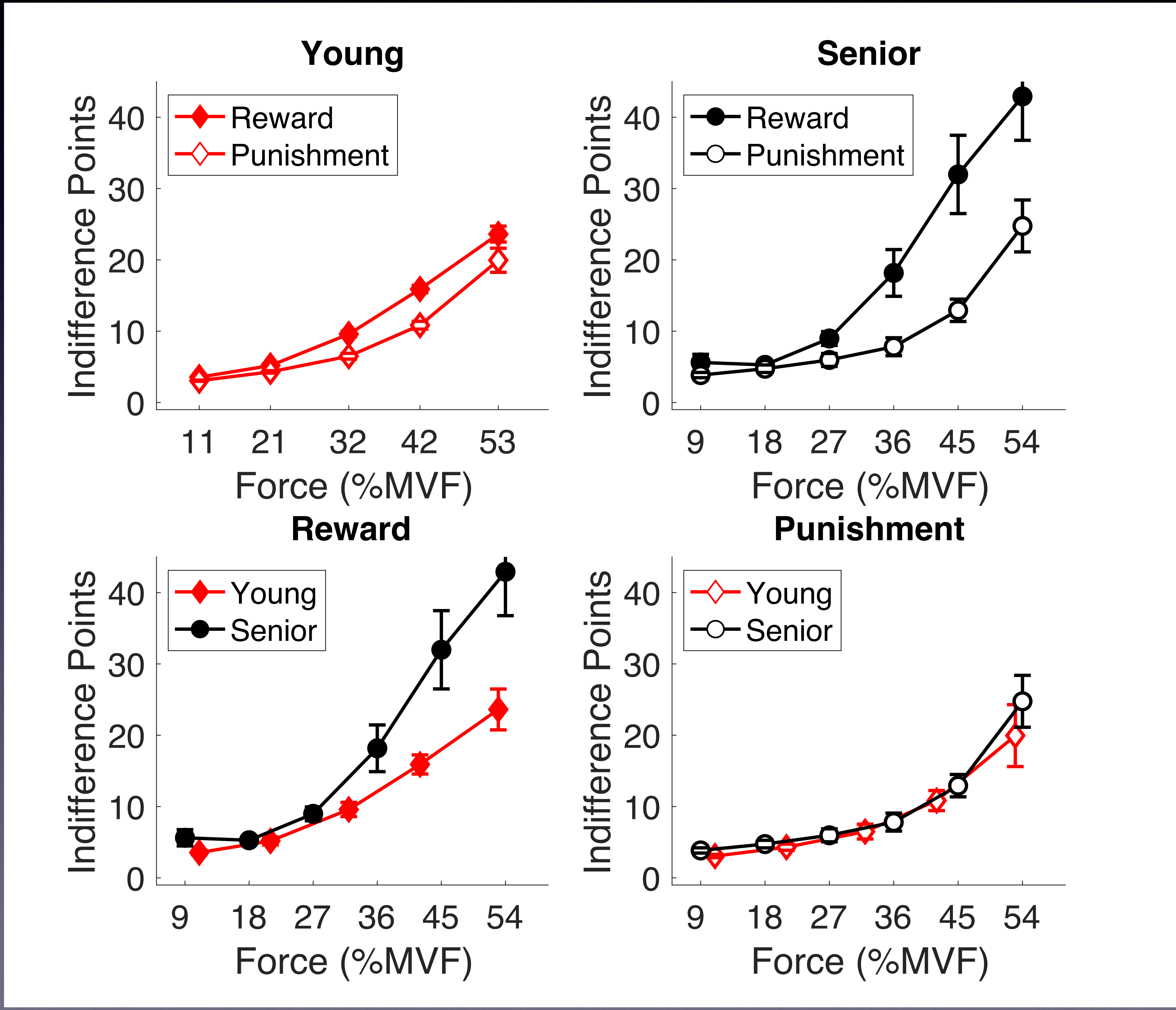
YES ~~15 points~~ → 0 points

NO ~~0 points~~ → -15 points



Chen et al., (in preparation)

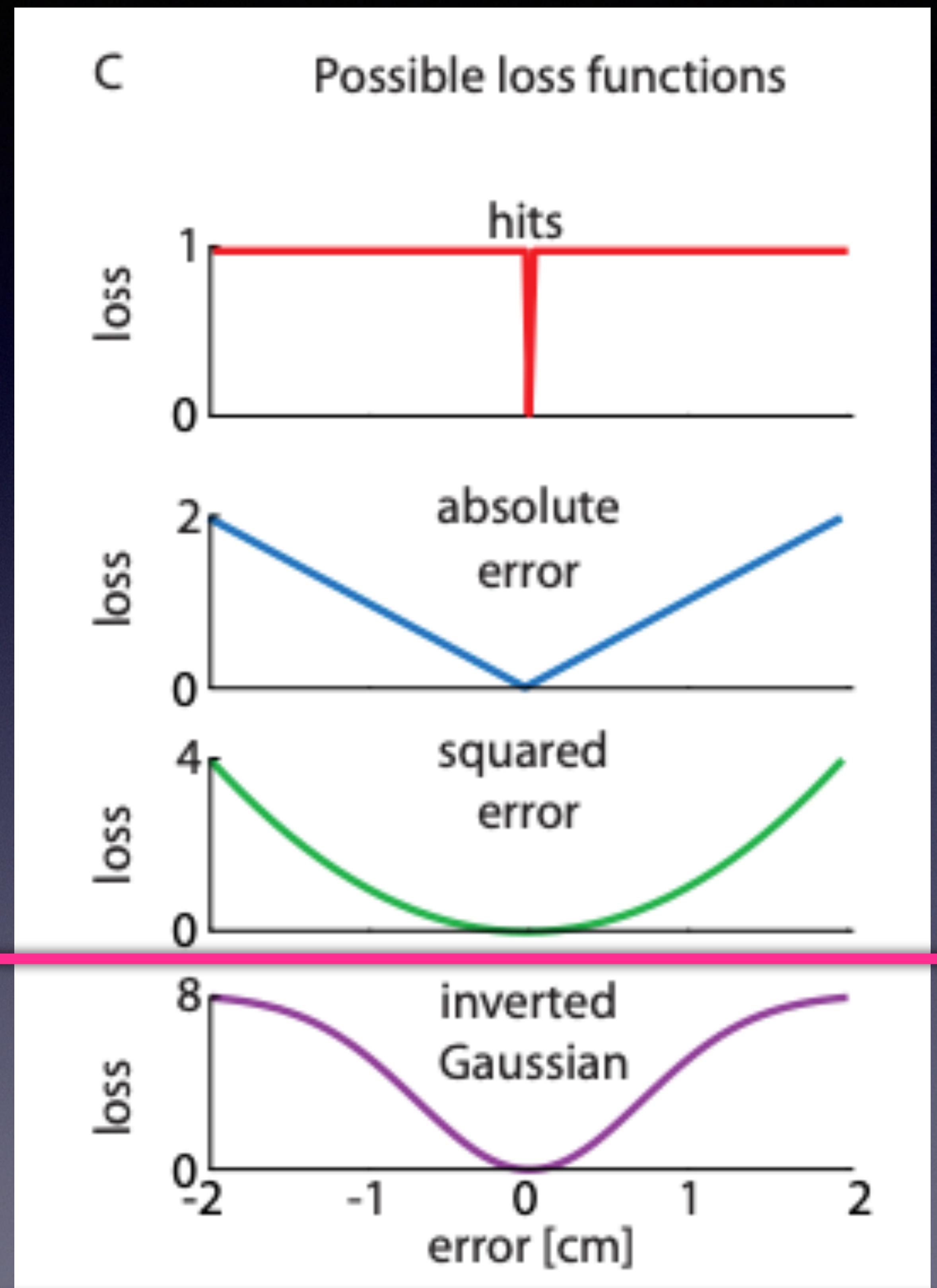
Example 1: Effort perception (ageing effect)



Chen et al., (in preparation)

Example 2: Spatial error

- Models of pointing task usually assume a quadratic loss function in which the mean squared error is minimised.
- However, deviations from this assumption have been found for large motor errors

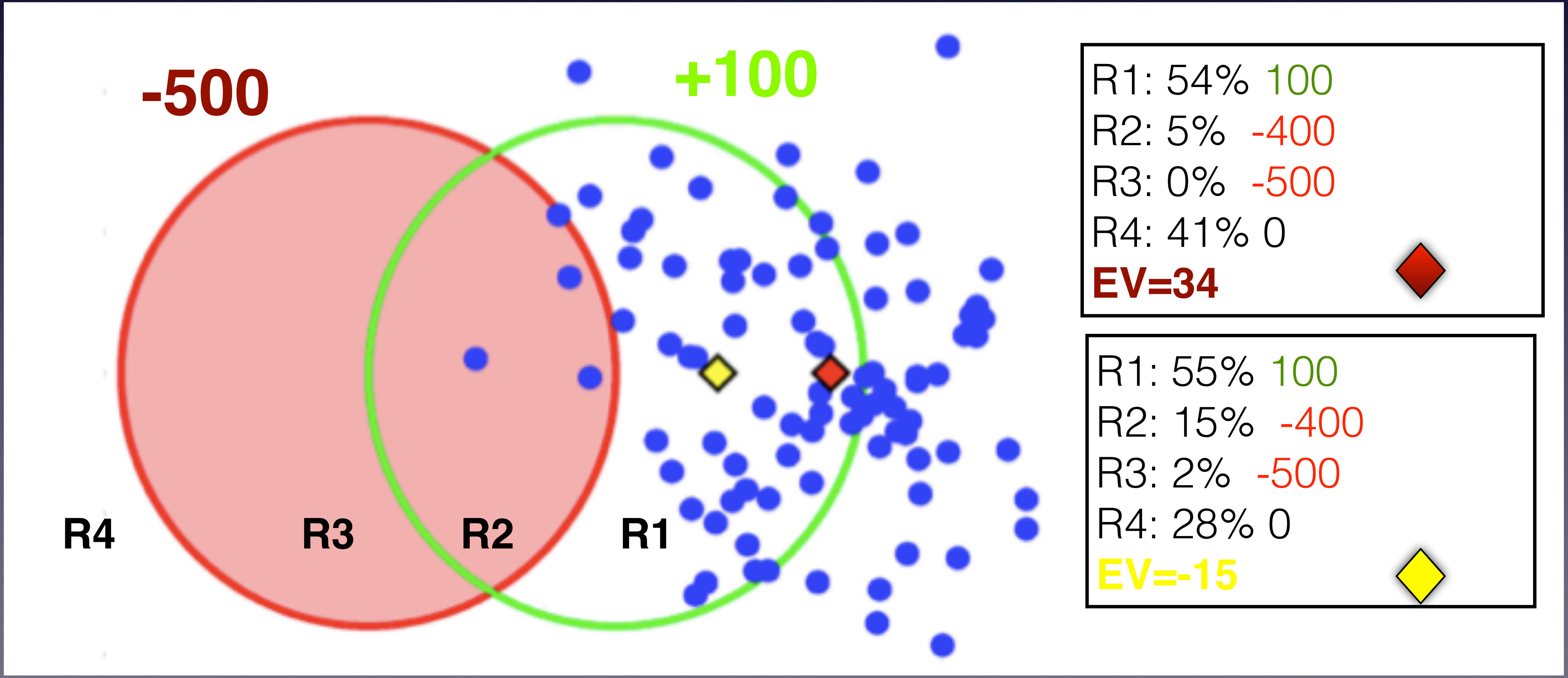


Körding and Wolpert, 2004b

Example 3: Risk sensitivity

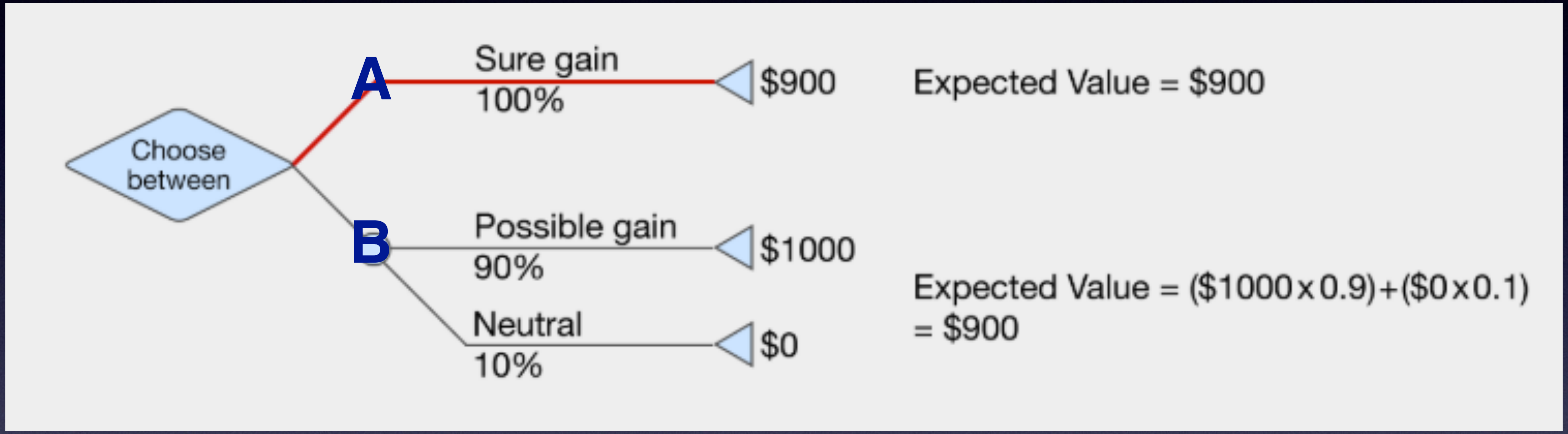
- **Movement planning and control as a problem of decision making in which the uncertainty plays a key role**

Expected value for each aiming point

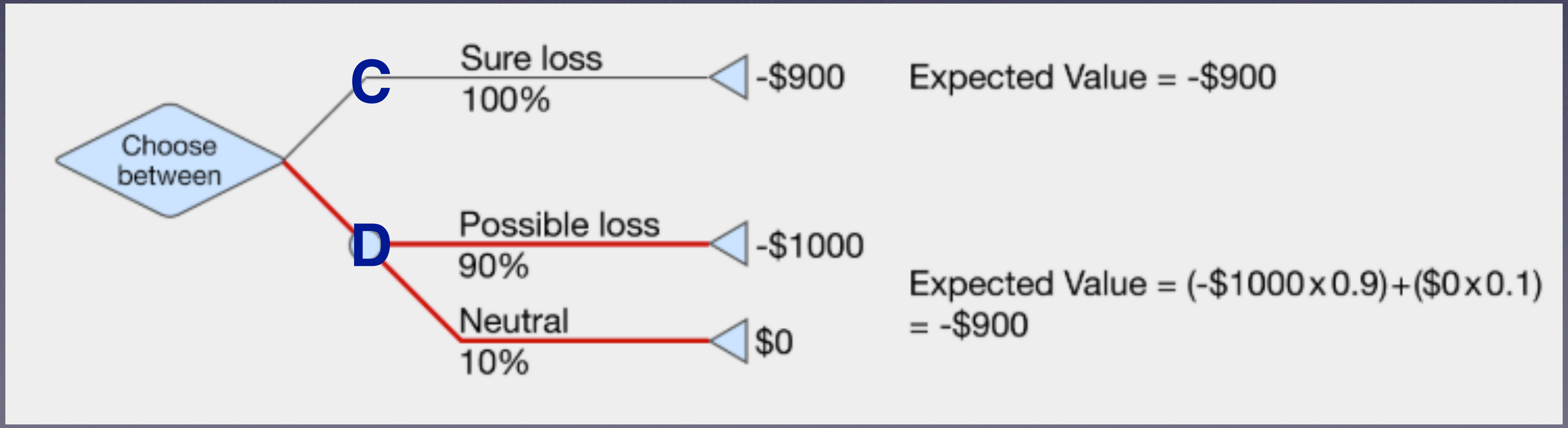


Example 3: Risk sensitivity (Prospect theory, Kahneman &Tversky 1979)

Risk averse in gain

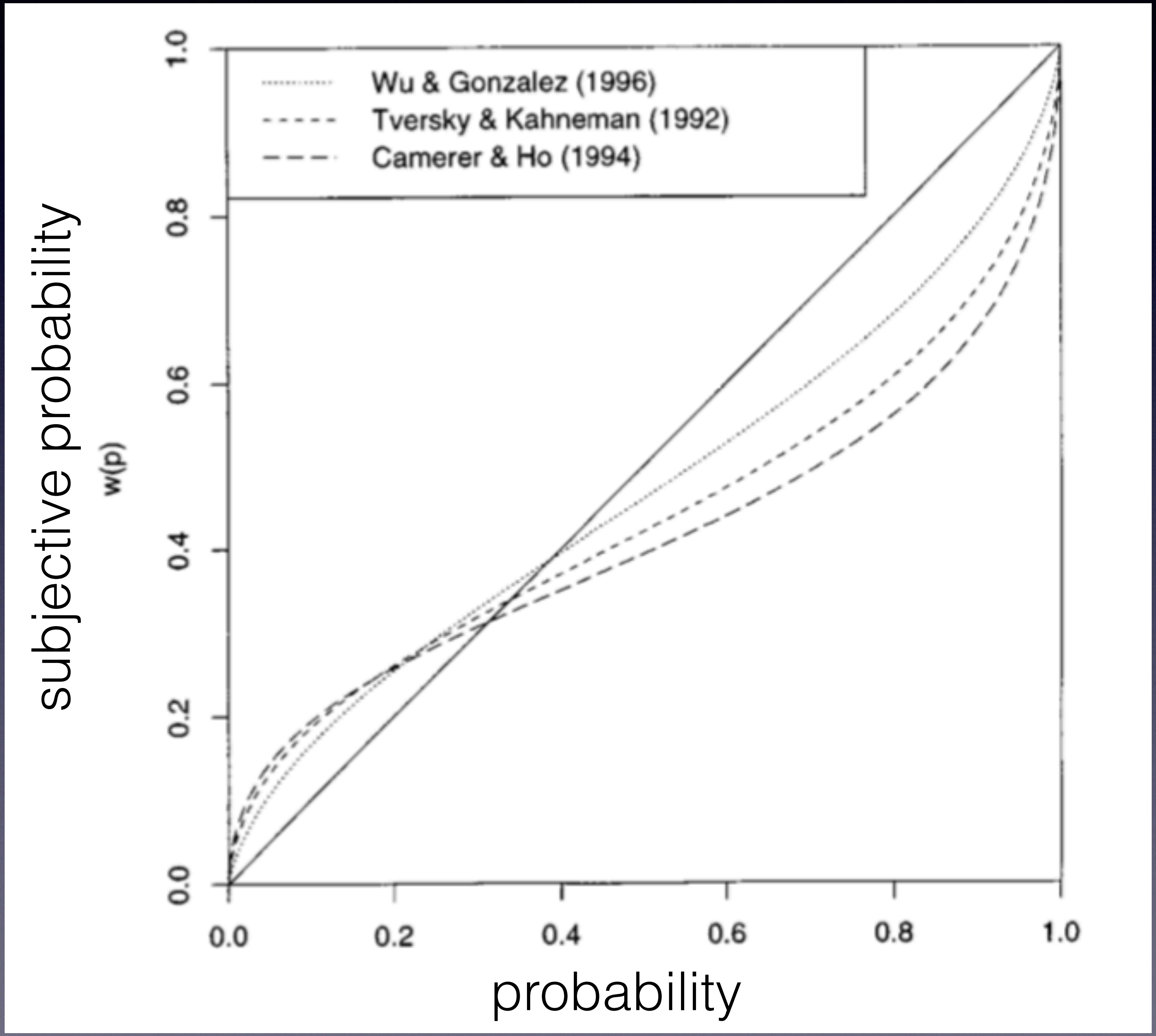


Risk seeking in loss



Prospect Theory, Kahneman &Tversky (1979)

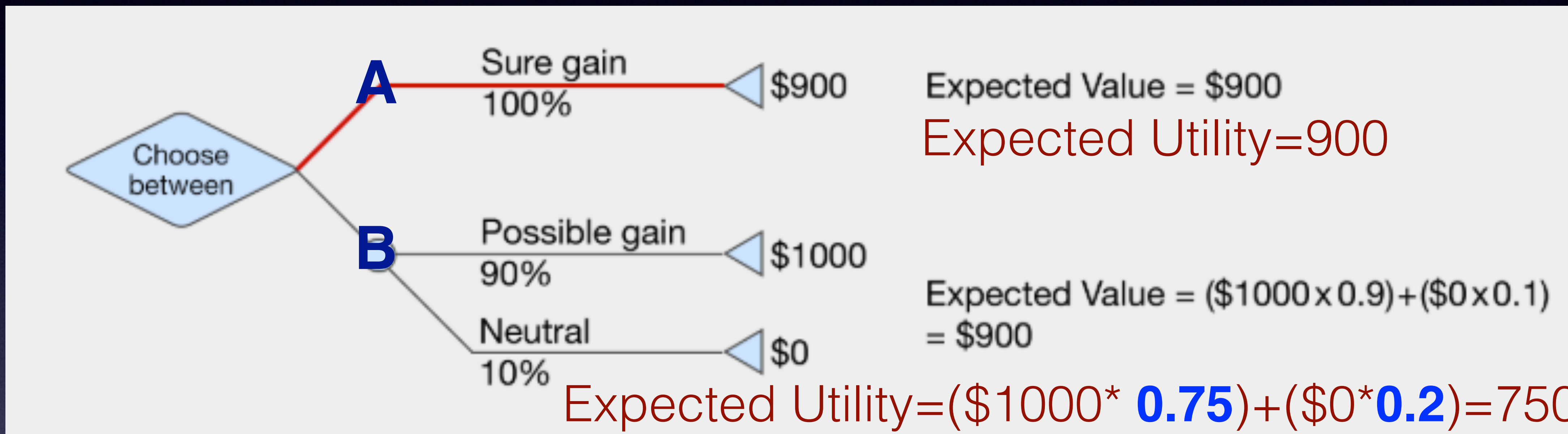
Example 3: Risk sensitivity



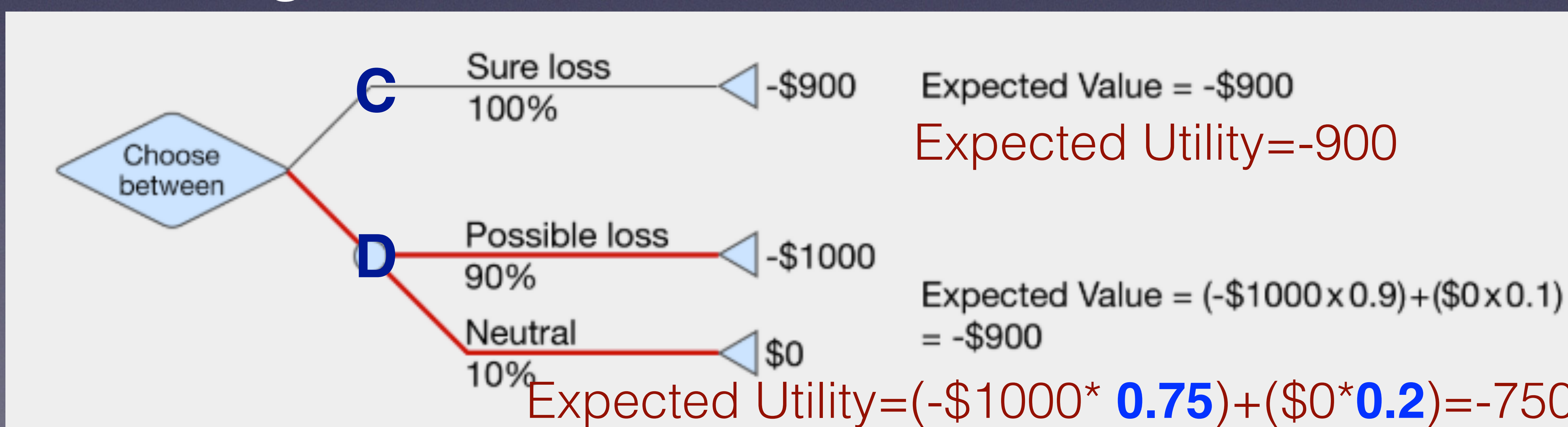
Prospect Theory, Kahneman &Tversky (1979)

Example 3: Risk sensitivity in economic decision-making

Risk averse in gain



Risk seeking in loss



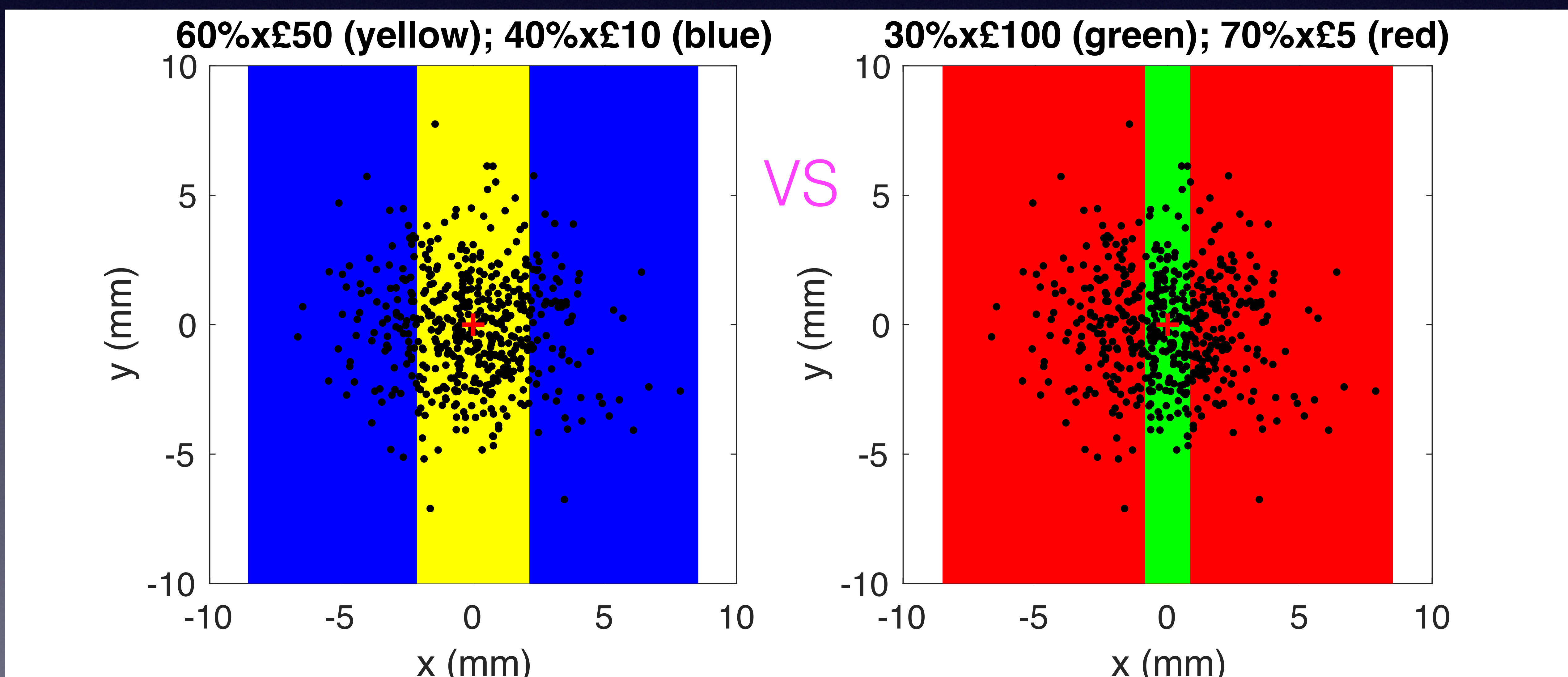
Prospect Theory, Kahneman &Tversky (1979)

Example 3: Risk sensitivity in motor decision making

60% £50
40% £10

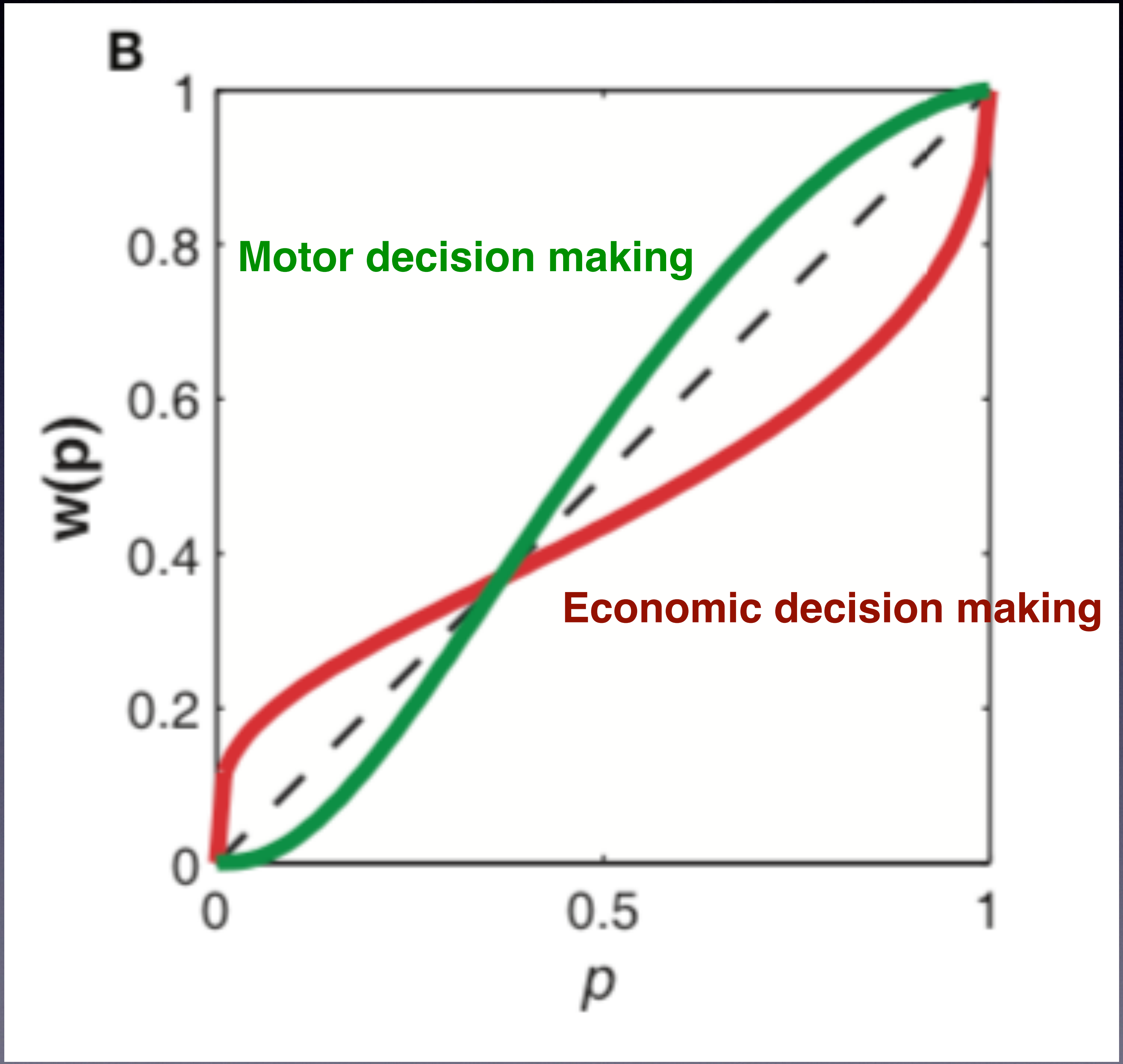
VS

30% £100
70% £5



Wu, S., Delgado, M. R., & Maloney, L. T. (2009). Economic decision-making compared with an equivalent motor task. *Proceedings of the National Academy of Sciences, 106*(15), 6088-6093. doi:10.1073/pnas.0900102106

Example 3: Risk sensitivity



Wu et al.,2009, Nagengast et al., 2010a,b

So humans are suboptimal? biased?

- ‘Systematic weirdness of human behaviour’ (Rahnev & Denison 2018)
- Rahnev & Denison 2018: “A great many discoveries have been made by explicitly rejecting optimality (e.g., Kahneman & Tversky 1979”)
- However…

Bound optimality (Computational rationality)

- An idea borrowed from artificial intelligence (Russell and Subramanian 1995): “An agent is bounded-optimal if its program is a solution to the constrained optimisation problem presented by its architecture and the task environment”.

- “Human behaviours are generated by cognitive mechanisms that are adapted to the structure of the external environment and also to the structure of the mind and brain itself” (Howes et al., 2009, Lewis et al., 2014).

Bound optimality (Computational rationality)

- Optimisation can be used by a scientist as a tool to determine the adaptive consequences of theoretical assumptions.

- The resulting predictive behaviour is compared to human behaviour.

- **Success is not used to conclude that people are either optimal or suboptimal, but rather, success indicates evidence in favour of the theory of the environment, bounded machine, and utility function.**

Example : randomness perception biases as rational response

- In coin flips, we believe HHHHH is less likely than HHHHT.
- Gambler's fallacy: Some gamblers believe that after a long sequence of red in roulette, an outcome of black is more likely on the next spin.
- However, as the statistician knows, both orders are equally likely to occur.

Hahn, U., & Warren, P. A. (2009). Perceptions of randomness: Why three heads are better than four. *Psychological Review, 116*(2), 454-461. doi:10.1037/a0015241

Example : randomness perception biases as rational response

- **Once the likely nature of people's actual experience is taken into account, the "biases" actually emerge as apt reflections of the probabilistic characteristics of sequences of random events**
- What constitutes rational behaviour, depends on the situational and environmental context in which that individual operates.

Example: randomness perception biases as rational response

....HTH $\boxed{\text{HHTTH}}$ HTHTHHTHTHTHT...

If the global sequence is of infinite length,
then, it can be shown that all possible (substring)
sequences are equiprobable.

Example: randomness perception biases as rational response

....HTHHHTTHHTHTHHTHTHTHT...

HTHHHTTHHTHTH$\boxed{\text{HHTHT}}$HTHT

Given people's finite resources
(and life span), any particular data stream that they might
experience—such as someone tossing a coin several times
over—is necessarily finite

Example: randomness perception biases as rational response

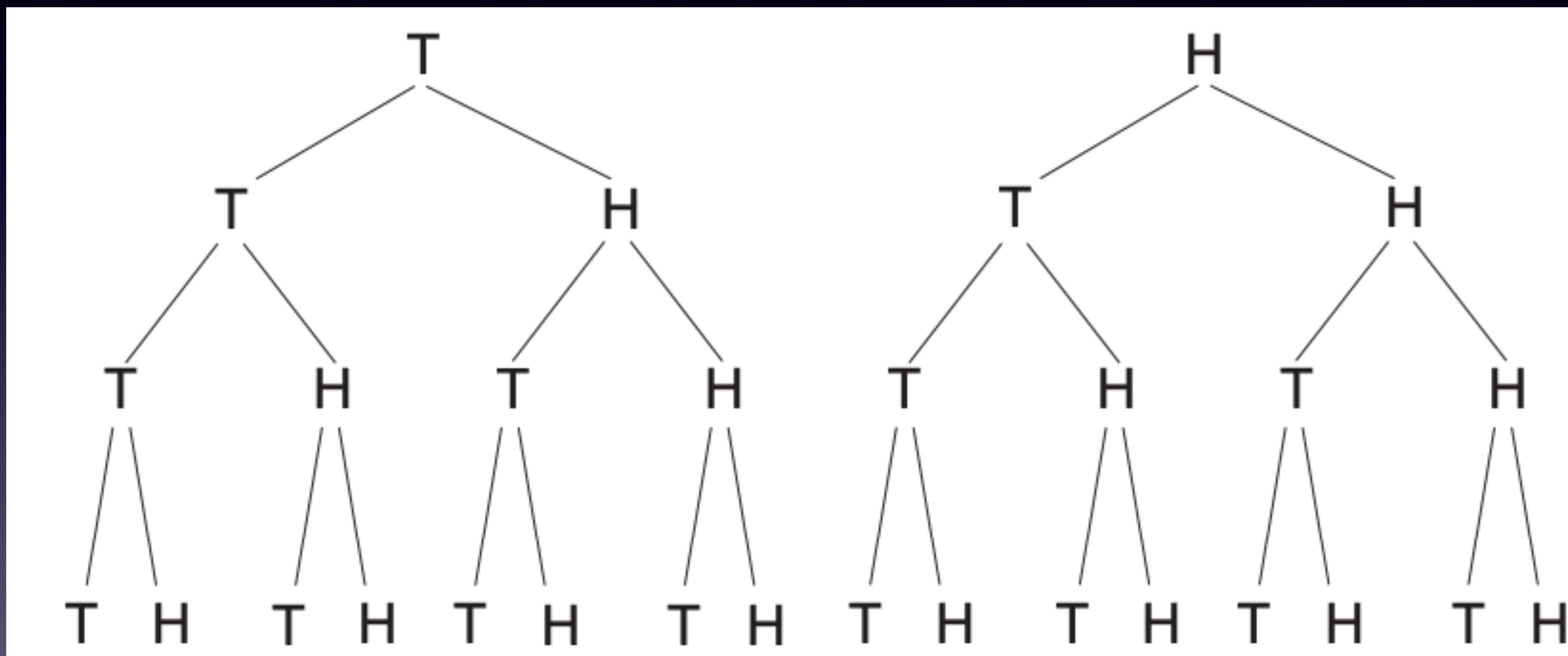
....HTHHHTTHHTHTHHTHTHTHT...

HTHHHTTHHTHTHHTHTHTHT

HTHHHTTHHTHT$\boxed{\text{HHTHT}}$HTHT

Furthermore, attentional and/or
memory limitations mean that people can hold in memory
concurrently only a limited number of observed items.

Example: randomness perception biases as rational response

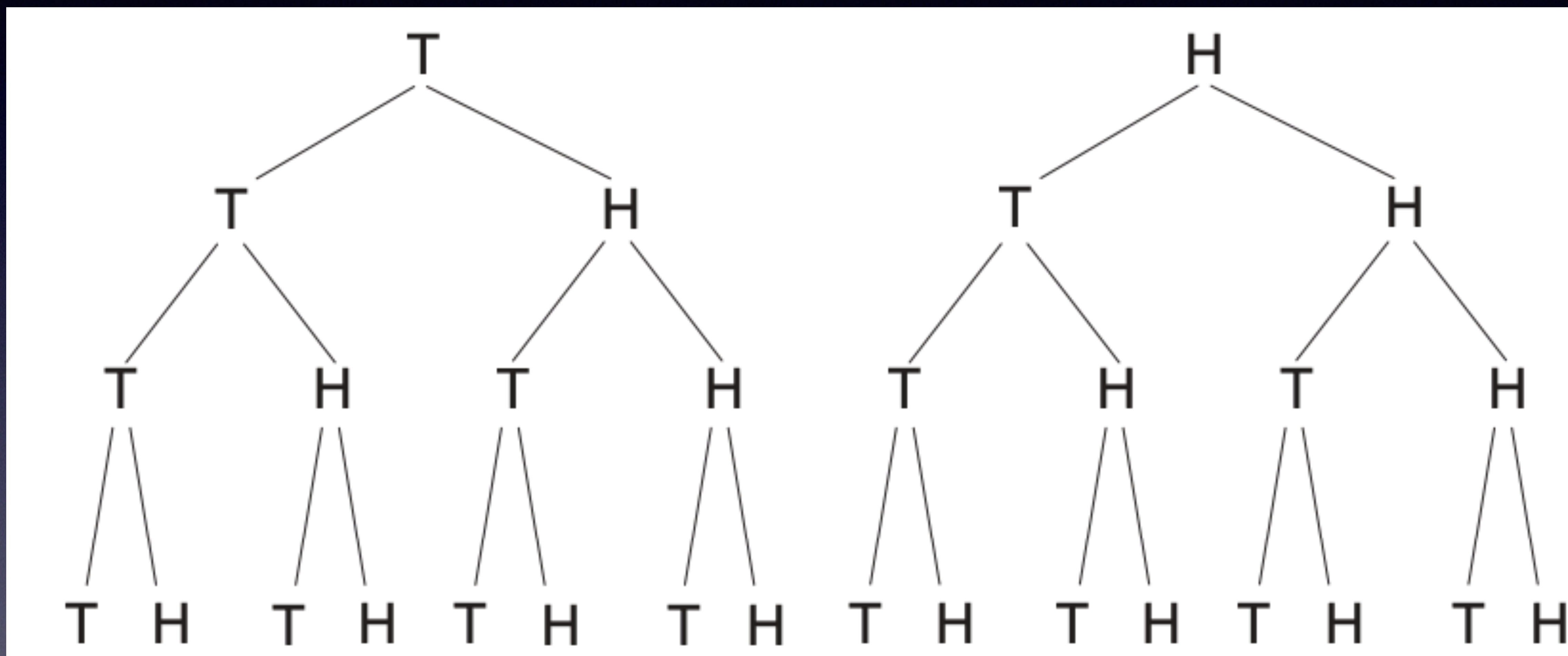


	1	2	3	4	5	6
HHH						
HHT						

Examine the case in which k=3 (substring) and n =4 (global sequence). Counting the number of occurrences of the exact orders HHH and HHT as local substrings within the global sequences represented by that tree.

Hahn, U., & Warren, P. A. (2009). Perceptions of randomness: Why three heads are better than four. *Psychological Review, 116*(2), 454-461. doi:10.1037/a0015241

Example: randomness perception biases as rational response



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
HHH								▲							▲	▲
HHT							◆						◆	◆	◆	

It is less likely to observe the local substring HHH within that global sequence than to observe the substring HHT.

Hahn, U., & Warren, P. A. (2009). Perceptions of randomness: Why three heads are better than four. *Psychological Review, 116*(2), 454-461. doi:10.1037/a0015241

More examples

- Acharya, A., Chen, X., Myers, C. W., Lewis, R. L., & Howes, A. (2017) **Human Visual Search as a Deep Reinforcement Learning Solution to a POMDP**, Proceedings of the Annual Meeting of the Cognitive Science Society , 51-56
- Vul, E., Goodman, N., Griffiths, T. L., & Tenenbaum, J. B. (2014). **One and Done? Optimal Decisions From Very Few Samples.** *Cognitive Science, 38*(4), 599-637. doi:10.1111/cogs.12101
- Howes, A., Lewis, R. L., & Vera, A. (2009). **Rational adaptation under task and processing constraints: Implications for testing theories of cognition and action.** *Psychological Review, 116*(4), 717-751. doi:10.1037/a0017187
- …

Summary

- Instead of a series of descriptive models of biases, the use of optimality approach offers better explanation of why humans do what humans do.
- Optimisation can be used by a scientist as a tool to determine the adaptive consequences of theoretical assumptions.
- The resulting predictive behaviour is compared to human behaviour.
- **Success is not used to conclude that people are either optimal or suboptimal, but rather, success indicates evidence in favour of the theory of the environment, bounded machine, and utility function.**