# Multi-tasking

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Language Processing and Aging

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Multitasking (phoning) while driving can be dangerous.

Now we want to look in a bit more detail at workload and multitasking.

Important questions:

- How are multiple tasks handled in the brain?
  (real parallelims? frequent switching between tasks?)
- What combinations of tasks are good / bad in terms of performance on both tasks?
- How does multitasking affect a) cognitive load and b) performance?

# Terminology

Mental workload is the portion of a humans limited mental capacities actually required to perform a particular task.

Mental reserves are the difference between capacity required and capacity available.

Mental effort is the voluntary matching of mental capacities with that needed for task success.

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**Increase in Mental Workload** often leads to **degradation in performance**, especially if more capacities are required than are available.

# Cognitive Load – Primary Task Performance

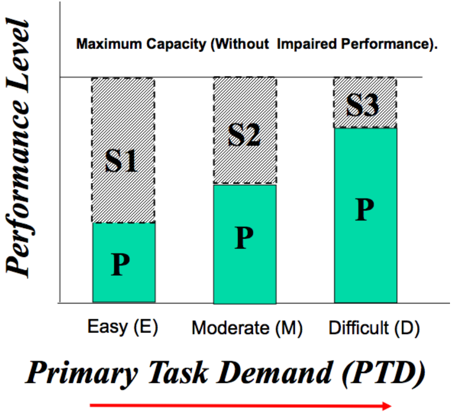
Measure performance: how well is the task done?

Disadvantages:

- “Mental Workload” not distinguishable from performance outcome
- Problem: insensitive to level of mental workload, as long as it is under capacity (performance at ceiling).
- Can’t predict whether making the task a little bit harder will push over capacity.

# Secondary task measure

Measuring on a secondary task when interested in cognitive load induced by primary task:




- tell subjects that primary task is more important
- observe secondary task performance
- performance on secondary task as correlate of primary task difficulty.
  (How much cognitive resource is left for the secondary task?)

(pic taken from P. Hancock)

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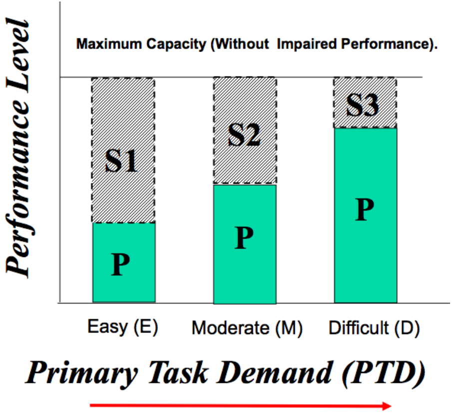


But how do the two tasks interact with each other?

(and in our case we're not interested in just workload of one task, but the workload of two tasks together.)

(pic taken from P. Hancock)

# How does multi-tasking work?

## Experiment with 2 tasks of equal priorities (Schumacher 2001)

1. Visual-manual task
   - circle appears in one of three positions
   - need to press corresponding button on keyboard
2. Aural-vocal task
   - tone in one of three possible pitches is played
   - say “one”, “two” or “three” depending on tone

Possible outcomes:

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Possible outcomes:

- answers on one of both tasks slower in dual task condition
- answers to both tasks take same amount of time as if it had been presented as single tasks. (“perfect time sharing”)
- (for tasks where primary and secondary task are correlated such that the signal is partially redundant, could possibly also get faster reaction times in dual task than single task)

# Schumacher 2001 results

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If both signals presented at same time:

- perfect time sharing (after training)

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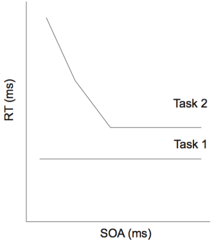


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If signals in sequence and additional instruction to respond to first one first:

- additional overhead “Perceptual Refractory Period”: processing of first stimulus not finished when second arrives, therefore delay.

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If signals in sequence and additional instruction to respond to first one first:

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If visual task harder (no direct mapping):

- no perfect time-sharing anymore: overlap in response generation

# Effects of practice

- Automatic processes can be executed in parallel
- Controlled processes subject to limitations
- Practice can convert controlled into automatic processes.

# Choice of tasks in multi-tasking

Task difficulty:

- harder tasks require more cognitive resources, so more difficult to multi-task
- harder tasks are more difficult to automate.

# Choice of tasks in multi-tasking

## Try it!


Try to rotate your foot clockwise and your hand counter-clockwise!

Task similarity:

- different tasks are easier to execute in parallel than very similar tasks.
- (similarity of complex tasks may be difficult to asses)

# Central Capacity Theory

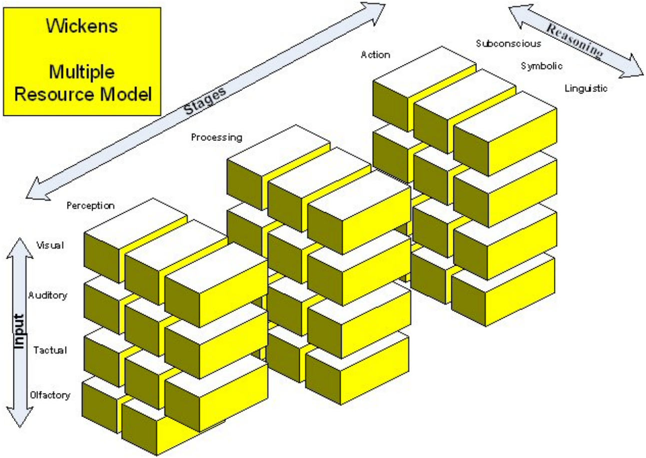
Kahnemann 1973 – basic ideas

- limited resources
- different processes must compete for cognitive resources

Explanatory adequacy:

- explains slow-down or lower performance in dual tasks
- but not why more similar tasks should be more difficult

# Multiple Resources Theory




Wickens 1984 - ideas

- each resource has limited capacity
- slowdown if two tasks overlap in terms of resources needed
- complementary tasks should not incur additional cost.

Can explain similarity effects and difficulty effects, but possibly a bit too parallel.

# Serial Bottleneck

Some agreement that there is parallel processing to some extent, but that there are also “serial bottlenecks”.

## Bottleneck 1: Psychological Refractory Period (PRP)

- response selection is limited
- Why?
  - effect of sharing limited resources?
  - a serial bottleneck (some part of the process that can’t be done in parallel)?
- neural correlates: PRP is thought to occur at time between stimulus consolidation in working memory and motor preparation (Marois & Ivanov, 2005)

## Definition

**Memory consolidation** is a category of processes that stabilize a memory trace after its initial acquisition.

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### Bottleneck 2: the attentional blink

Capacity limit in explicit visual event detection: the attentional blink

- first stage of massively parallel processing of incoming stimulus
- later stages of processing require attention and are capacity-limited
- task: identify two targets in rapid succession, frequent failure to identify second target

$\rightarrow$ demo

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## Bottleneck 3: visual short term memory

- capacity estimate: four items
- also affected by complexity of items
- difficult to detect small changes in complex scenes
- capacity also dependent on attention
- inattention blindness when focussing on something else

$\rightarrow$ demo

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# Serial Bottleneck

Some agreement that there is parallel processing to some extent, but that there are also “serial bottlenecks”.

Conclusions:

- maybe what’s limited is short-term memory consolidation, needed both for AB and PRP.
- Open question: do the observed limits come from limited resources of attention, or limited processing / parallelisation in a specific information channel (visual / aural etc.)?

### Definition

**Memory consolidation** is a category of processes that stabilize a memory trace after its initial acquisition.

# Answers to our initial questions

- How are multiple tasks handled? (real parallelims? frequent switching between tasks?)
  $\rightarrow$ not quite conclusive, but full parallelism unlikely
- What combinations of tasks are good / bad in terms of performance on both tasks?
  $\rightarrow$ minimize overlap of resources needed; the more automatic the better
- How does multitasking affect a) cognitive load and b) performance?
  $\rightarrow$ multitasking can lead to an overhead in load, and/or worse performance on one or both tasks.

# Back to our task: driving and (remote) conversation

Strayer and Drews (2007)

- Inattention blindness: drivers fail to *react* to relevant objects or events on the road if they are phoning, even if looking at the objects:
  in dual task condition don't react more to relevant objects than irrelevant ones $\rightarrow$ no deep semantic processing
- drivers react more slowly when distracted.
- EEG: brain activity associated with driving related tasks was reduced when driver was speaking on the phone.
- Tunnel vision: when distracted, drivers scan the road and mirrors less; fail to look at important road-side objects.

# Bottlenecks and Inattention blindness

- we perceive lots of information at the same time.
- our brain must always decide what to act on.
- Stages of prioritizing and processing information:
  1. Select and Process
  2. Encode and Store
  3. Retrieve and Act

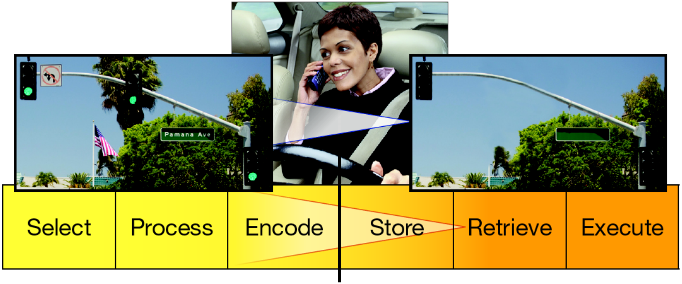


Figure 1. Inattention blindness and encoding.
Source: National Safety Council

# Overall summary

Users can (and want to) perform multi-tasking

- increased efficiency compared to forced serialization
- but performance CAN suffer
- interference effects dependent on type of tasks and task difficulty
- if we can manipulate the difficulty of one task, we can hopefully increase performance on other task

# Second part

Let's look at some results from our lab.

# Linguistic complexity matters!

Talking on mobile phone or hands-free device is more dangerous during driving than talking to a passenger (e.g. Crundall et al., 2005).

**WHY?**

# Linguistic complexity matters!

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**WHY?**

Passenger *adapts* to traffic situation

- **fewer utterances** when driving on city course as opposed to rural route (Crundall et al., 2005)
- **complexity of speech of passenger** and driver lower in difficult driving (Drews et al., 2008)

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**Dialog systems should be more like passenger drivers and less like the remote conversational partner.**

# Does the linguistic form really matter?

Questions:

- Does the linguistic form really matter?
- Can we measure that?

Dual task experiment: driving and language comprehension

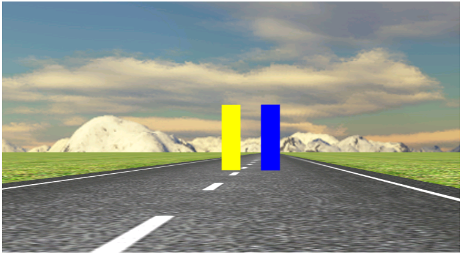
# Experimentelle Methoden

# The driving task

Choosing a suitable driving task:

**realistic**
- good for testing general driving ability, and strategies
- many rare events

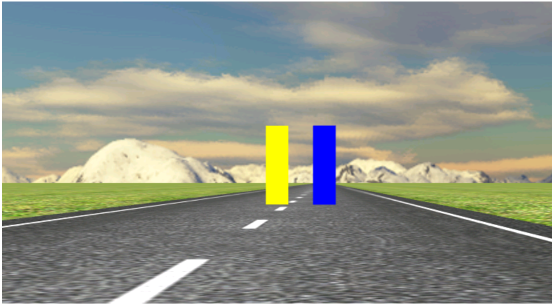
**ConTRe**
- good for measuring impact of subtle manipulations
- well controlled and continuous



Continuous Tracking and Reaction (ConTRe) task (Mahr et al., 2012) plug-in for OpenDS
`www.opends.eu`

# Experimental setting

ConTRe driving task



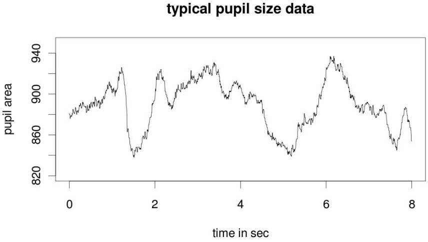
**Performance measure:**

- Steering deviation

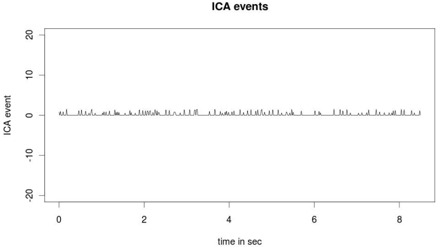
**Measures of cognitive load:**

- Skin conductance
- Pupil size
- Index of Cognitive Activity (ICA)

# Index of Cognitive Activity (ICA; Marshall, 2000)



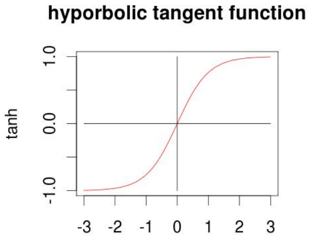

*wavelet analysis* ↓




**Traditional Pupillometry:**
overall pupil size
linked to cognitive load.

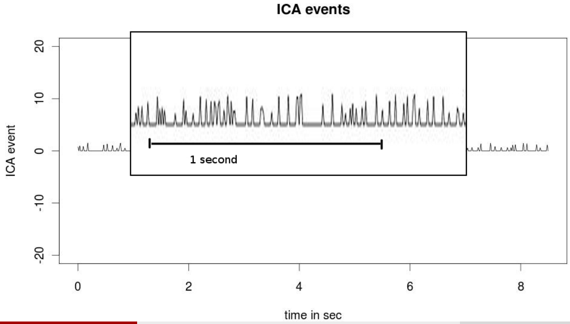
**Index of Cognitive Activity:**
frequency of rapid dilations interpreted as sign of cognitive load.

# How is the ICA calculated?




**Calculation of ICA (Marshall, 2000)**

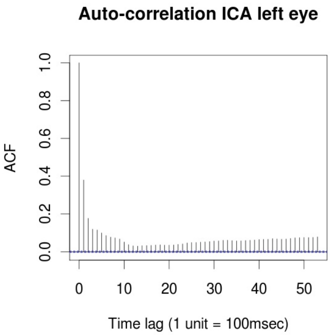
- ICA = $\tanh\left(\frac{\text{\# of rapid dilations per sec}}{30}\right)$

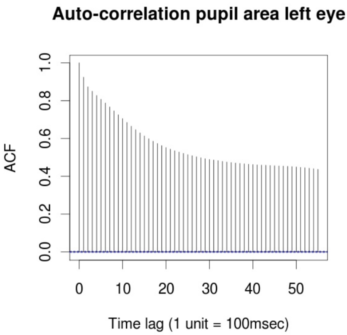


# Properties of the ICA

**Properties of ICA**

- more robust wrt. changes in light / movement
- more dynamic



# Background: What does it mean?

- Pupil dilation is strongly correlated with activity in locus caeruleus (LC)
- LC neurons are bilateral and emit the neuro-transmitter norepinephrine (NE)
  (Aston-Jones and Cohen, 2005)
  (Laeng et al., 2012)
- LC-NE system activated by stress
- related to memory retrieval and memory consolidation

## Relationship pupil – LC neuron

Relationship between tonic pupil diameter and baseline firing rate of an LC neuron in monkey.

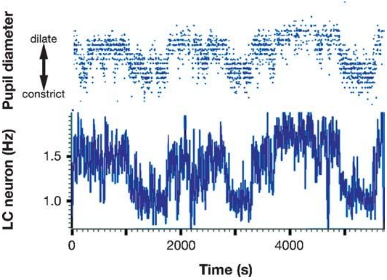



Figure taken from Aston-Jones and Cohen (2005).

# Experimental procedure

- 24 participants aged 20-34

**Driving task settings**

| condition | easy | difficult |
|---|---|---|
| target bar | 1m/s | 2.5m/s |
| controllable bar | 2m/s | 4m/s |

| | |
|---|---|
| Training Driving | 2 min |
| Training Driving + language | 1 min |
| Break | |
| Driving | 2 min |
| Driving + language (10 items) | 4 min |
| Break | |
| Driving | 2 min |
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| Break | |
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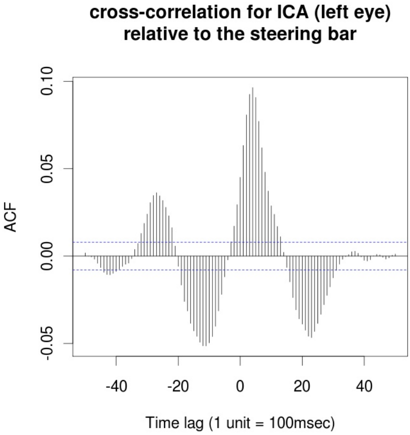
| Driving + language (10 items) | 4 min |
| Break | |
| Driving | 2 min |
| Driving + language (10 items) | 4 min |

# ICA and driving (single task)



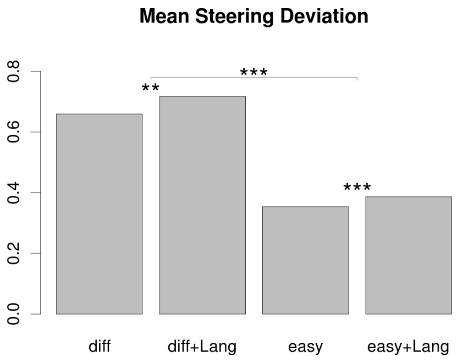

- More rapid pupil jitters right after subjects move the steering wheel.
- But no significant correlations for this in any of our other measures (skin conductance, overall pupil dilation)
- Individuals who had smallest steering deviations had largest ICA effects.

# Experimentelle Methoden

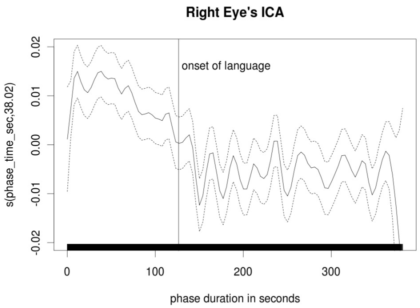
Does the language task measurably affect driving performance?

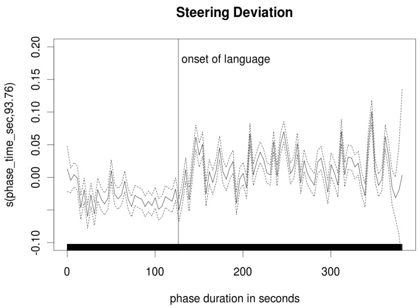
# Results: Steering Deviation

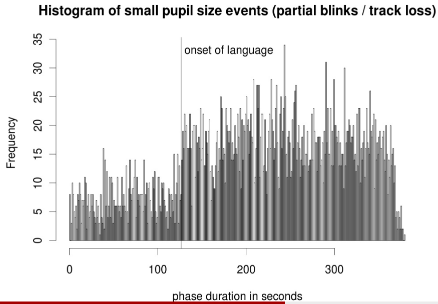
**Yes, steering is significantly worse during dual tasking.**

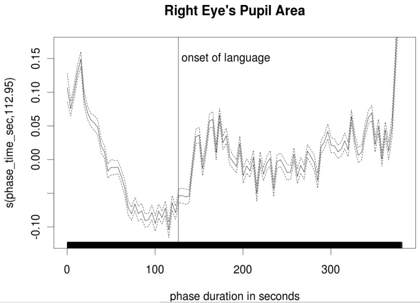



Interaction also significant:
language has a larger effect in difficult driving setting


Right Eye's ICA
onset of language
s(phase_time_sec,38.02)
0.02
0.01
0.00
-0.01
-0.02
0
100
200
300
phase duration in seconds


Steering Deviation
onset of language
s(phase_time_sec,93.76)
0.20
0.15
0.10
0.05
0.00
-0.10
0
100
200
300
phase duration in seconds


Histogram of small pupil size events (partial blinks / track loss)
onset of language
Frequency
35
30
25
20
15
10
5
0
0
100
200
300
phase duration in seconds


Right Eye's Pupil Area
onset of language
s(phase_time_sec,112.95)
0.15
0.10
0.05
0.00
-0.10
0
100
200
300
phase duration in seconds

But does the linguistic complexity of a sentence matter?

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*Die Nachbarin, [die$_{sg,n/a}$ einige$_{pl,n/a}$ der Mieter auf Schadensersatz verklagt* ***hat***$_{sg}$*/* ***haben***$_{pl}$*]$_{RC}$, traf sich gestern mit Angelika.*

"The neighbor, [who sued some of the tenants for damages / whom some of the tenants sued for damages ]$_{rc}$, met Angelika yesterday."

- Comprehension question after half of the items.
- 40 items and 80 fillers

# Language ICA in dual task

**Yes, the ICA is significantly lower (= less pupil twitch) in the easy linguistic condition compared to the difficult one.**

- No effects on pupil size; skin conductance

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| | coefficient | signif |
|---|---|---|
| (Intercept) | 0.7504 | *** |
| subject RC | -0.0354 | * |
| phase time | $-1.16 \times 10^{-7}$ | * |
| time wrt. onset | $-2.78 \times 10^{-5}$ | *** |
| steering veloc | 0.0257 | *** |
| steering accel | 0.0108 | * |
| SRC:phase time | $1.34 \times 10^{-7}$ | * |

Table: Mixed effects regression analysis with **left eye's ICA** as response variable, 650–1800msec after onset of *hat / haben*. (Critical region duration: 0-650msec)

# Steering Performance

Can we observe an effect of the linguistic manipulation on **steering performance**?

# Steering Performance

**People steer worse during the disambiguating region than before or after.**

| | coefficient | signif |
|---|---|---|
| (Intercept) | 0.3562 | *** |
| phase time | $8.459 \times 10^{-8}$ | *** |
| target velocity | 0.3832 | *** |
| critical region | 0.0139 | ** |
| easy driving | -0.2248 | *** |
| target acceleration | -0.0268 | *** |

Table: Mixed effects regression analysis with **steering deviation** as response variable, for region of 2s before the onset till 2s after end of the critical region.

# Steering Performance

**During disambiguating region, steering deviation gets larger in ORC condition compared to SRC.**

| | coefficient | signif |
|---|---|---|
| (Intercept) | 0.368 | *** |
| time since onset | $1.402 \times 10^{-5}$ | |
| subject RC | 0.0478 | |
| phase time | $1.247 \times 10^{-7}$ | * |
| easy driving | -0.2478 | *** |
| target velocity | 0.3586 | *** |
| timeOnset:SRC | $-5.915 \times 10^{-5}$ | ** |

Table: Mixed effects regression analysis with **steering deviation** as response variable, for region of 200ms till 1200ms after onset of the critical region.

# Experimentelle Methoden

# Conclusions

**Methods for assessing fine-grained cognitive load during driving:**

ConTRe task:

- controlled and continuous task
- suitable for testing effect of fine-grained manipulations

Index of Cognitive Activity (ICA):

- relates processing difficulty to the frequency of rapid dilations
- more robust measure than traditional pupil size
- significant effects in expected direction for both steering and language comprehension task

**Linguistic form matters:**

- Linguistic complexity has a measurable effect on driving safety.
- Dialog systems should adapt the way they speak to user and situation.