Using Information to Drive Decisions

NICTA

Cognitive Load Measurement Through Multimodal Behaviours

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Australian Government

Department of Broadband, Communications and the Digital Economy

Australian Research Council

NICTA Members

ANU

UNSW

NICTA Partners

The University of Sydney

Griffith University

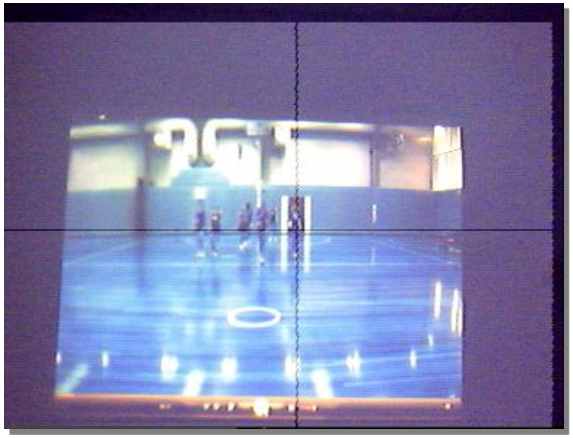
The University of Queensland

About NICTA

- National ICT Australia
  - Federal and state funded research company established in 2002
  - The largest research organisation in Australia dedicated to ICT
  - ~750 staff/students working in 5 labs across major capital cities
  - Headquarters at Australian Technology Park (ATP)

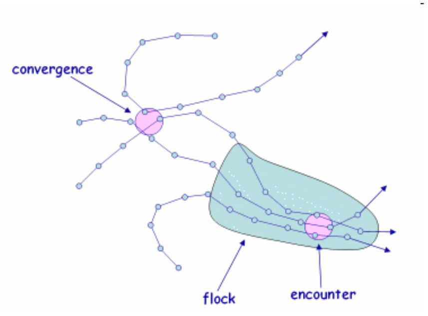
Making Sense of Data Theme @ ATP

- Decision Support for Incident Management
  - Cognitive Load Measurement and Management in complex real-life situations
  - Optimising joint human-system integration via cognition-aware adaptive Interfaces
- Human Performance Improvement
  - Cognitive Load Measurement in the field (e.g. athletes)
  - Skill Acquisition, Field Training/Lab training
  - Real-time feedback of performance



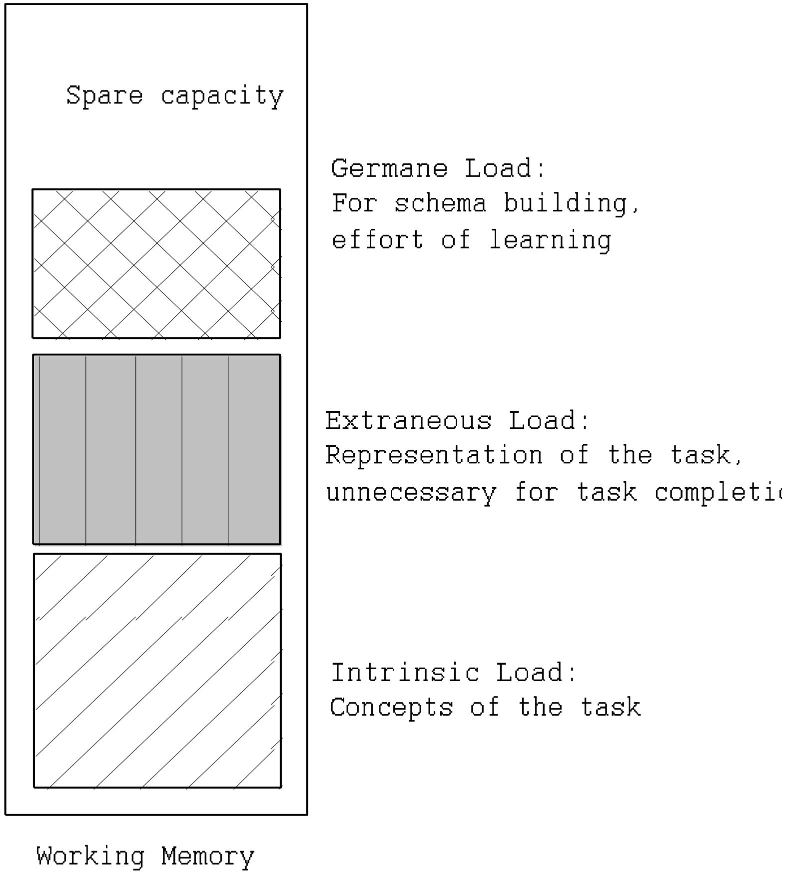
Making Sense of Data Theme @ ATP

- Collaborative human-machine interaction
  - NICTA/DSTO/CSIRO
  - Information sharing technology that can help geographically distributed teams collaborate more effectively
  - How to improve the productivity of teams and team members' awareness of co-workers Group Behaviour
- Geographical data mining
  - Analysing movement of objects (e.g. cars, people, animals) and trying to find interesting patterns such as where animals meet to form a flock
- Multimodal interfaces
  - Different input/output technologies
  - Multimodal information interpretation and fusion
  - Human multimodal behaviour patterns



Cognitive Load Theory [Sweller et al. 98]:

- Definition
  - Level of perceived effort associated with learning, thinking and reasoning (including perception, memory, language, etc)
  - Available 'space' in working memory in comparison to the 'space' needed by a user to complete the task successfully



Need for CL Measurement

- Overloading or underloading of cognitive processing:
  - Degradation of performance, and/or
  - Failures of learning and performing, and/or
  - Source of performance errors.
- CL measurement is crucial for:
  - Minimising the amount of cognitive effort required,
  - Maintaining the right level of CL,
  - Achieving adaptive system response,
  - Improving user performance.

State-of-the-Art CL Measurement

- Subjective (self-report) measures
  - Users rank their experienced level of load on single or multiple rating scales;
  - Consistent and reliable over time
    - Lickert Scales
    - Semantic Differential Scales
    - NASA-TLX
- Performance measures
  - Testing, error rates, accuracy, time to response etc…
  - Do not always reflect load levels; load may increases well in advance of performance degradation

State-of-the-Art CL Measurement

- Physiological measures
  - Heart rate, galvanic skin response, blood pressure,
  - Pupil dilation, eye movement,
  - Electroencephalograph (EEG) , Event Related Potential (ERP),
  - Positron emission tomography(PET), Magnetic resonance imaging (MRI)

- Behavioural measures
  - Speech, mouse speed and pressure,
  - linguistic or dialogue patterns,
  - other multimodal behaviour such as gesture and pen input
  - Still under exploration…

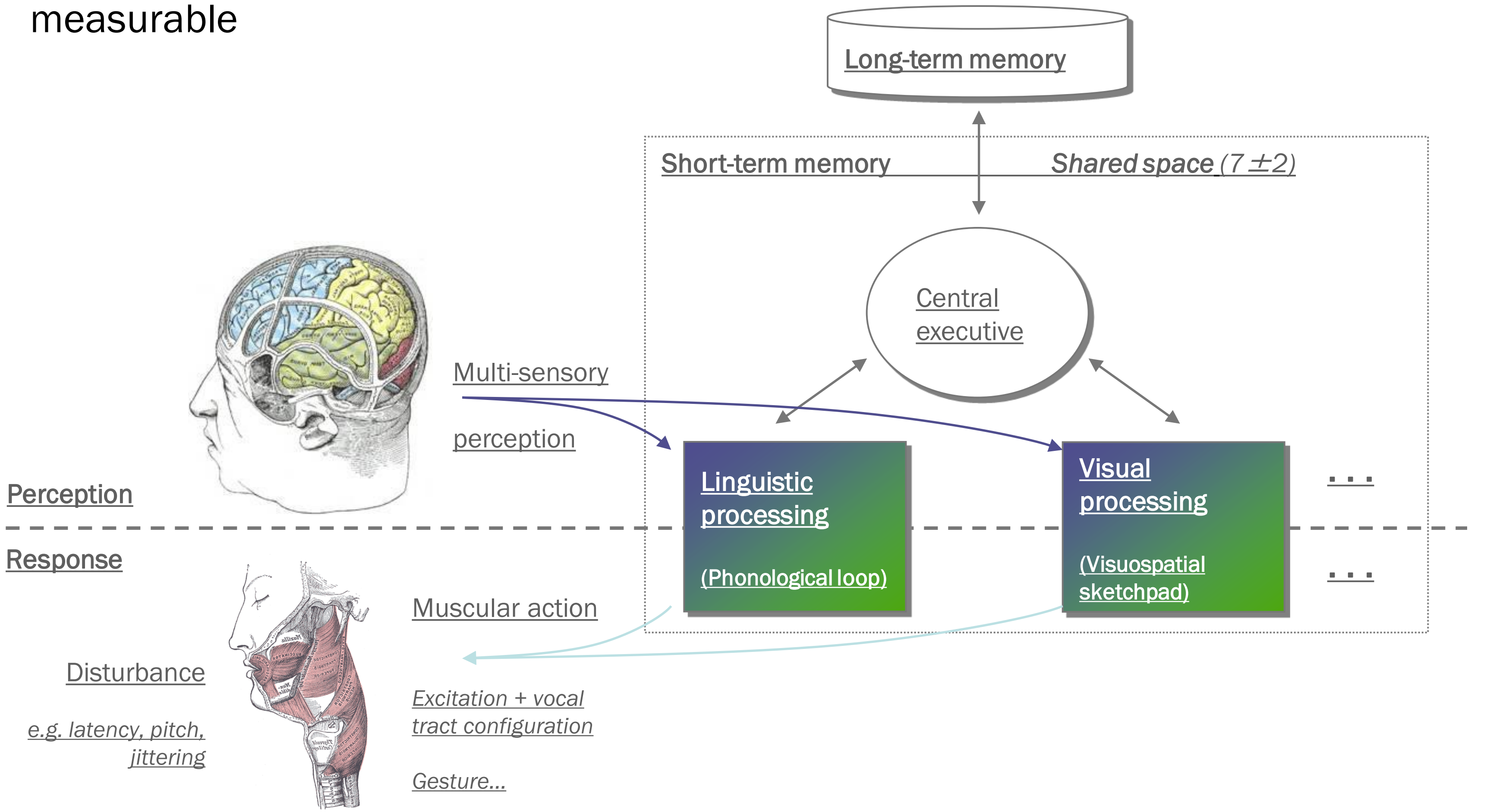
Ideal Measurement

- Expected measurement should be
  - Accurate
  - Objective
  - Real-time (online)
  - Non-intrusive (for most scenarios)
  - Reliable
- Solutions
  - Behavioural methods are suitable but depend on the task scenario
  - Physiological methods can be used if possible

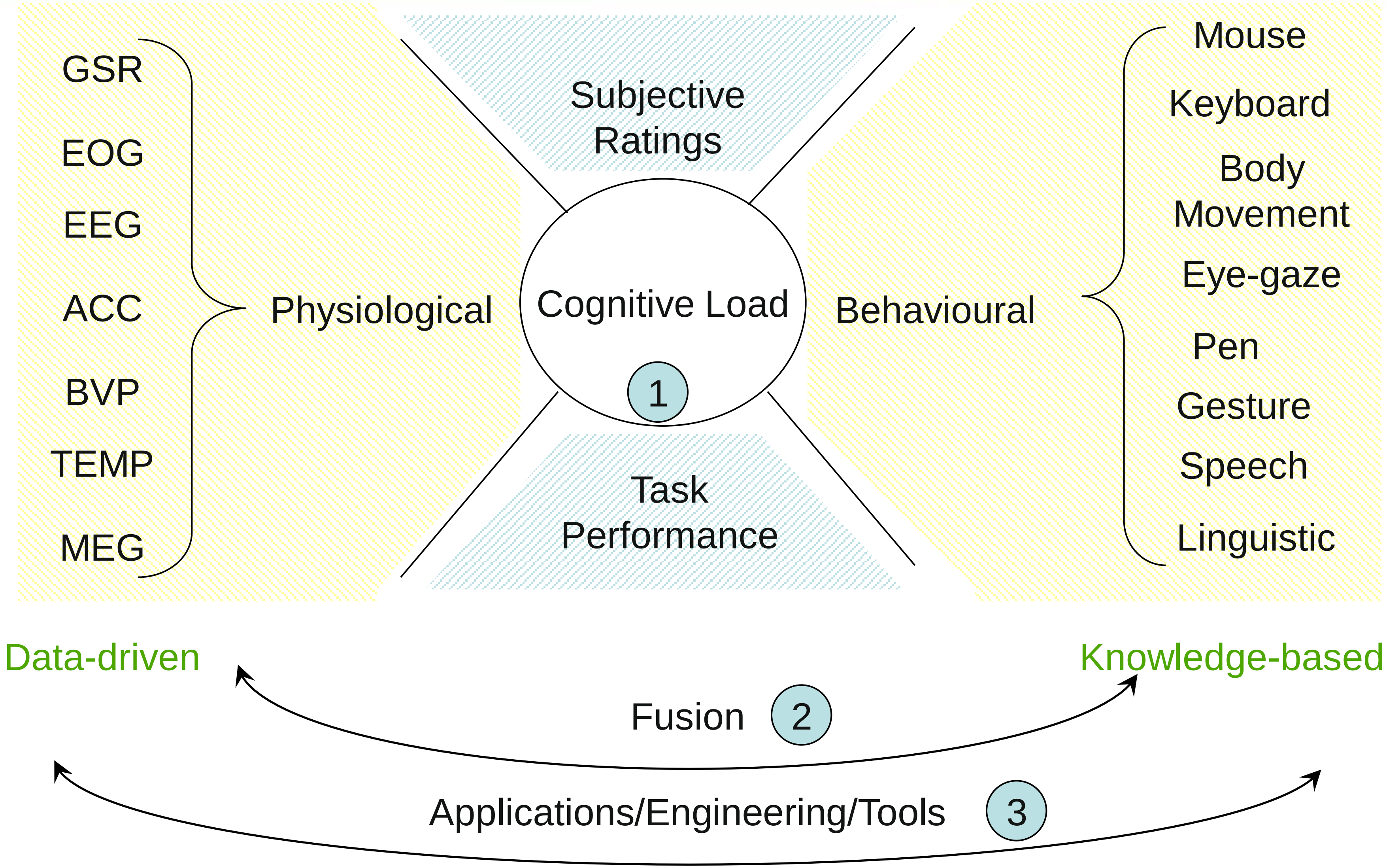
High cognitive load and human responses

- Disturbance in responses caused by high cognitive load may not be perceptible to humans, but may be machine measurable

E.g. Baddeley's Modal Model of Working Memory



Multimodal Cognitive Load Indices



Applications of CLM

- Real-time Operational Load Management
  - Cognitive load assessment in simulated environment
  - Assessment of the operational processes
  - Identification of training needs
- System/Device/Web Usability Evaluation (User Centered)
- Adaptive Interaction Design
- Staff Recruitment

CLM
Science/Technology

Call Centres
Simulations
/Training (CAE)
Defence/Military

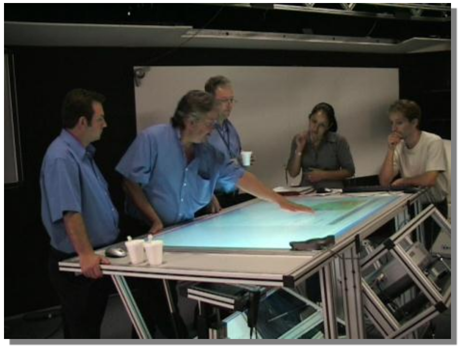
Traffic Management
Road Traffic (RTA, Transurban)
Air Traffic Control

Emergency Centres
Bushfire, Ambulance, SES

Usability, Hearing aids, cochlear implants, Health Monitoring and rehabilitation...

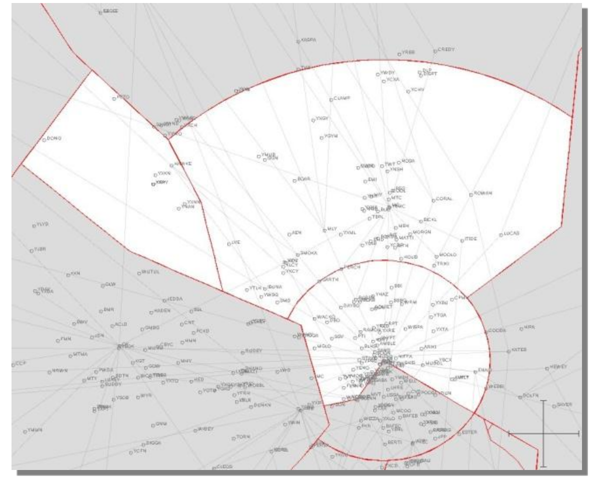
Incident Management

- **5 years partnership with RTA Transport Management Centre**
  - Re-design of existing interfaces (user centred design)
    - Experiments, workshops, focus groups, interviews
  - Cognitive load evaluation
    - Developed a rigorous methodology
    - Optimising the interaction performance
- **3 years work with Bushfire management**
  - four states (TAS, VIC, NSW, and QLD), Three roles: Incident Controller (IC), Planning, Operations, 11 exercises, 33 subjects, 33 Hours data.
  - Cognitive load evaluation
  - Recommendations on adaptive interfaces



Collaborative work with BushFire CRC

CLM in Air Traffic Control



Collaborative work with NICTA QLD

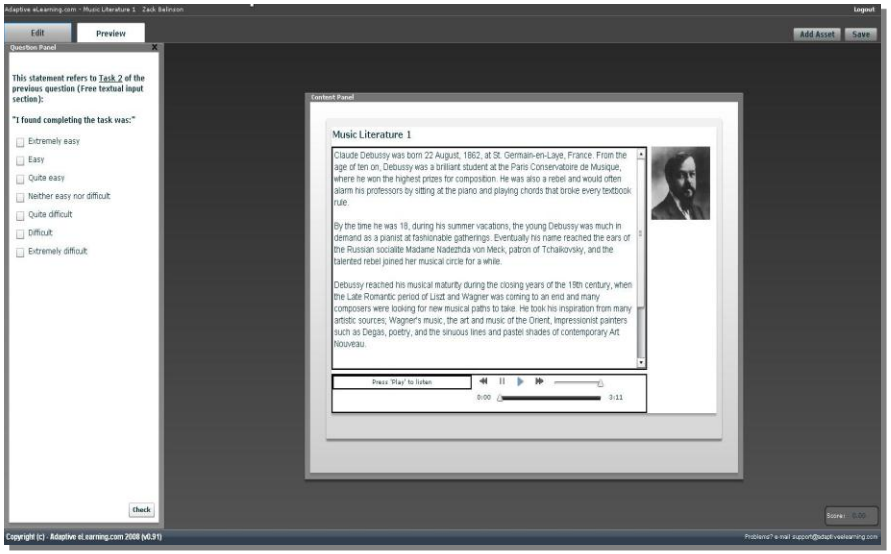
1 2 3 4 5 6 7 8 9 10

Low workload Could accomplish everything easily.	Moderate workload Could accomplish everything, but took some effort.	High workload Could accomplish everything, but was difficult and took considerable effort. Assistance would not be needed.	Extreme workload Extremely difficult to accomplish everything. Assistance would be needed.

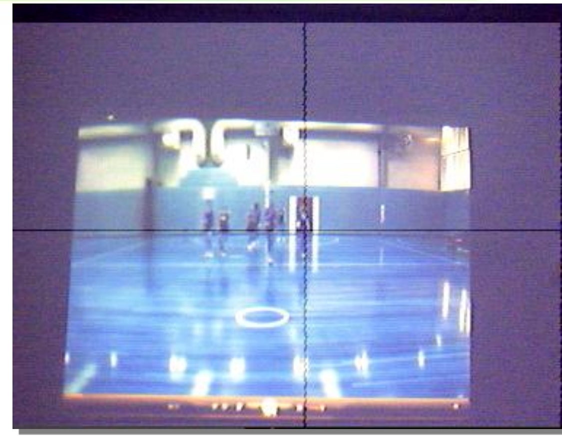
Accuracy: **ATC area 1 100.0%** **ATC area 2 85.7%** **ATC area 3 83.3%**

Based on: 3 airports, 7-8 operators per airport, 3x30min sessions for each operator

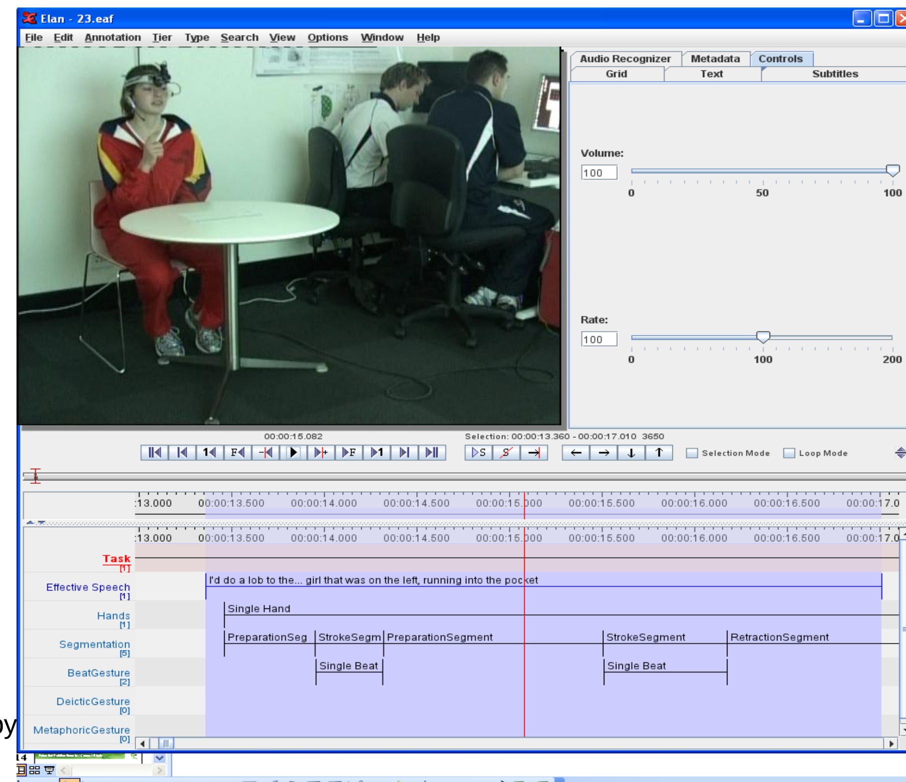
Education interface / Training tool



Collaborative
work with UNSW

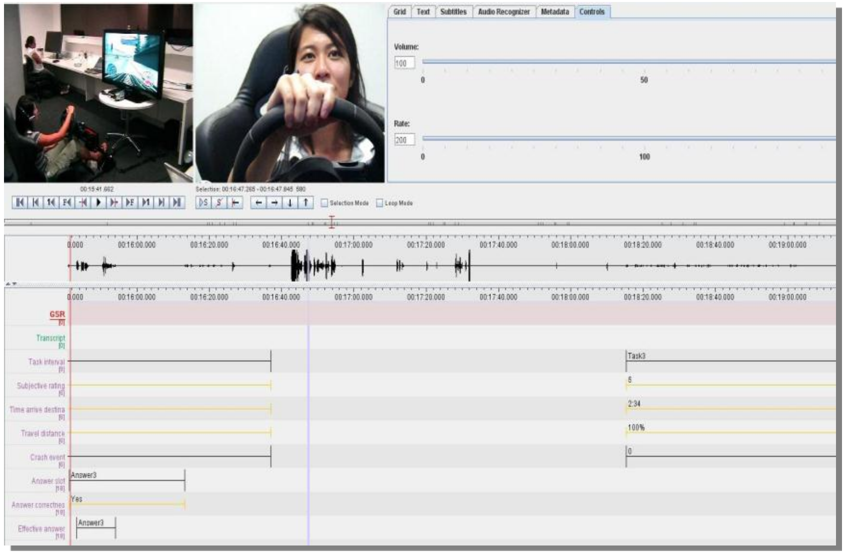


Exploring the application of technological approaches to distant learning & skill learning



Collaborative
work with AIS

In-car Cognitive Load Measurement



Collaborative work with the University of Gothenburg,, Sweden

Data

- Front camera for eye movement
- Rear camera for driver action
- Wireless headset for speech
- Bio-sensor for GSR
- Accelerometer for driver body movement

Data

- Camera 1 for front view
- Camera 2 for driver close-up
- Headsets for driver's and passenger's speech
- Event recorder for buzzer and reaction
- IDIS – transmission, acceleration, break, steering actions

Research Outputs

- 130 Publications (since 2005) on HCI, and Cognitive Load Modelling and Measurement
  - Book Chapters
  - Journals
  - Conferences including: CHI, IUI, INTERACT, MMSP, ICASSP and InterSpeech
- Patents
  - Measuring Cognitive Load (Multimodal), filed in Australia, US, Canada.
  - Measuring Cognitive Load (Speech Content Analysis), filed in Australia, US
  - Speech Front Eng, filed in Australia

CLM Commercial Trials

- Technology
  - **World first speech based** working system
  - Language and task independent
  - **Patented** technology and validated in real-life situations
- Solution
  - **Software** based solutions – easy deployment
  - **Flexible integration** options – easy installation
- Current Clients (Call Centers)
  - Company A
    - **Fortune 500**, 12 Call Centres in 6 countries
    - Leading IT distributor and service provider
  - Company B
    - Biggest Flight Simulator Provider
  - Company C
    - Largest Australian outsourcing call centre

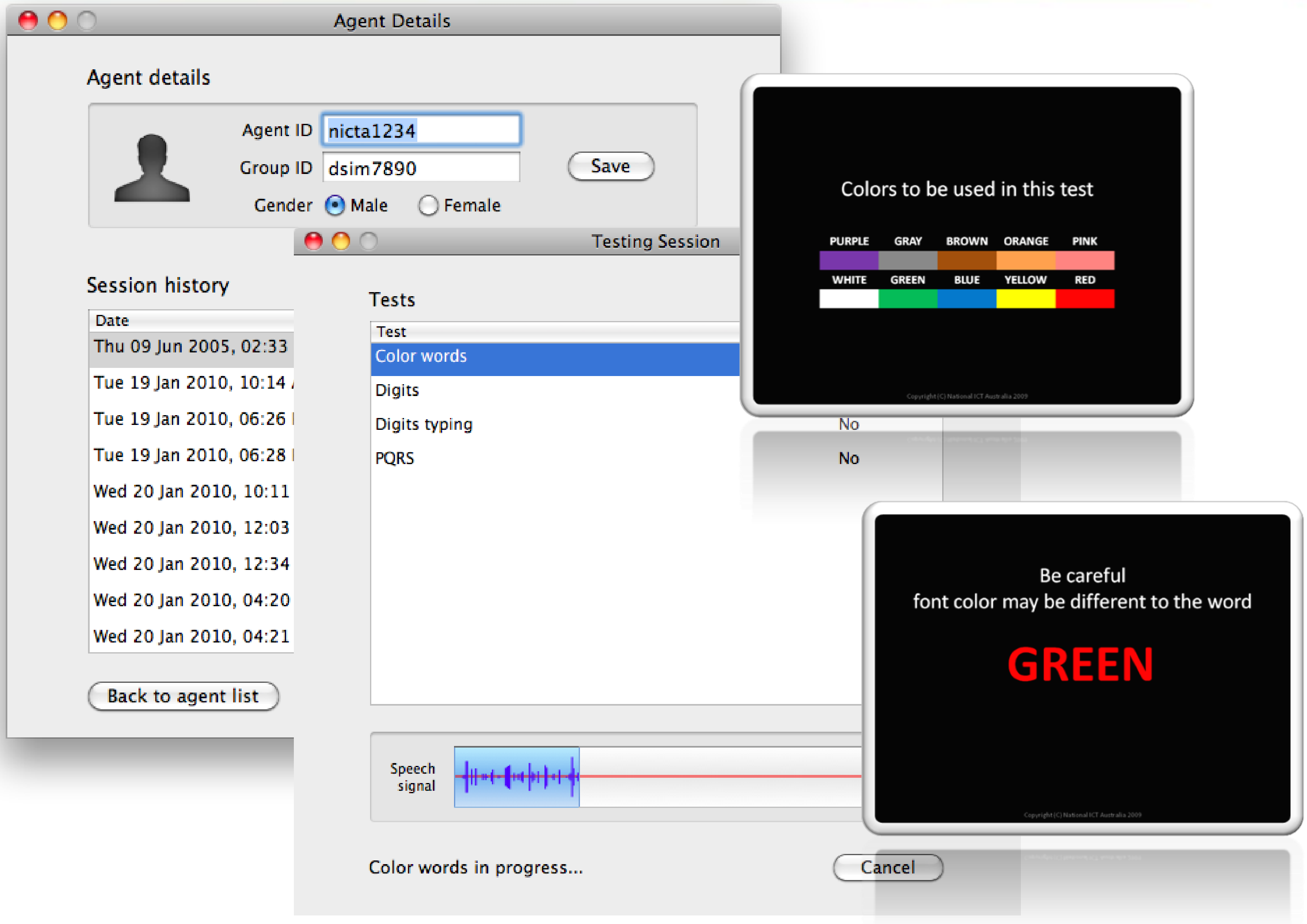
Our Solutions – BrainGauge

Solution to measure and predict agent capability as a:

- Recruitment Tool
  - Assess the candidate’s capability of performing task under high pressure
- Capability Tracking Tool
  - Identify training needs
  - Ensure optimal job/task allocation
- Cognitive Load Monitoring Tool
  - As a dashboard for load management

http://www.braingauge.com.au/

Recruitment Tool

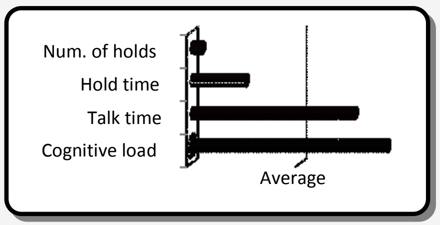


Dashboard for Management

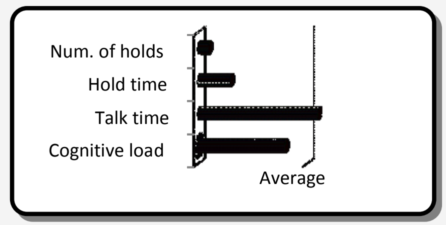
CLM for Quality Monitoring

- Real-time indication of cognitive load
- Call screening and tagging: normal / suspicious
- Hot spots identification

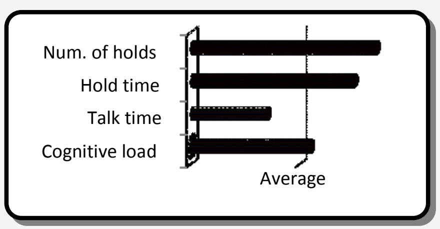
Agent 1



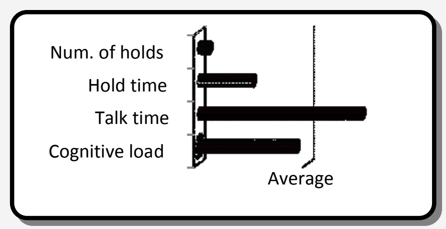
Agent 2



Agent 3

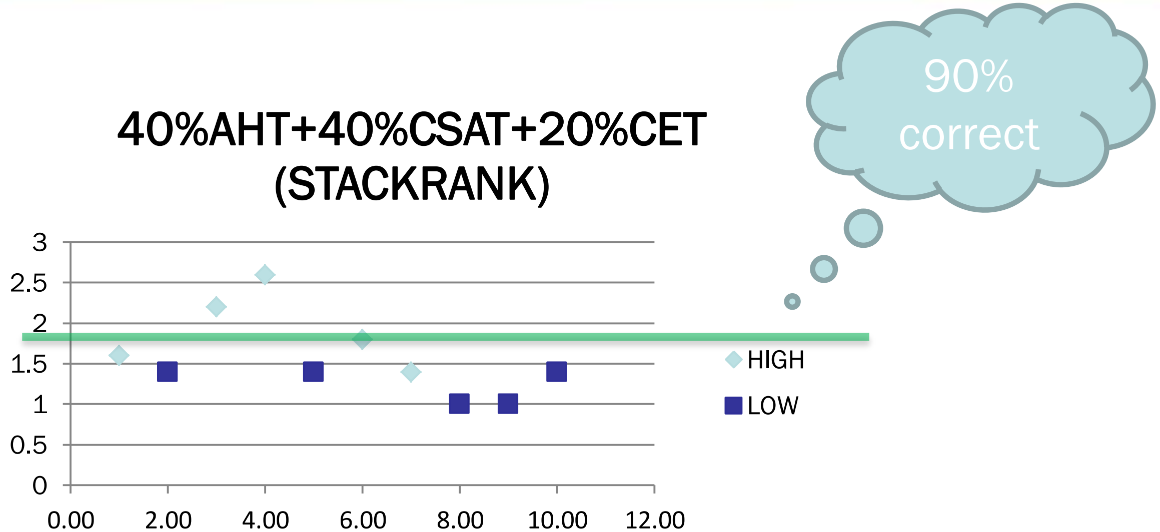


Agent 4



Statistics	First call resolution	67%	Avg. talk time	3min23sec
	Customer satisfaction	70%	Avg. hold time	0min54sec
	Quality score	62	Avg. cognitive load	1.6

Performance Prediction for New Hires



First trial with Company A (Fortune 500) finished. Results are encouraging:

- 40% wasted recruitment and training costs could be saved
- Average attrition rate could be reduced by 28.6% within 8 weeks, long term reduction rate can be higher
- Predicted performance band is highly correlated to the existing performance ratings

Exploring Speech Features

Speech-based Measurement

- Advantages
  - Passive
  - Non-contact
  - Easy to deploy, cost effective
  - Online
- Why speech?
  - Prior art shows sensitivity in the speech modality
  - Non-intrusive, relatively easy to collect, e.g. phone calls, interactions, conversations
  - Objective measure, not easily manipulated by the user
  - Real-time analysis is possible (for some speech signal features)
  - Widely available, in a number of application scenarios
- Challenges
  - Quantitative and consistent features
  - Automatic feature extraction
  - The variation of the working memory capacity among different people

Related Literature

- Existing research
  - In 1999, Berthold investigated potential speech features which could indicate the high cognitive load in a user modelling context
    - Two features, higher frequencies of sentence fragments and the decreased articulation rates, proved to be closely related to high levels of cognitive load.
  - In 2001, Muller conducted a similar experiment with time pressure as the primary source of cognitive load in a navigation task
    - A dynamic Bayesian network was used for learning the patterns related to speech features.
    - Six speech features were utilised, including disfluencies, articulation rate, utterance content quality, number of syllables, silent and filled pauses (err/uhm etc)
  - In 2006, Further investigation was carried out by Jameson, under an extra condition of background acoustic distraction
  - All of them focused on feature analysis without much research on automatic measurement

Speech Cues Related to Cognitive Load (CL)

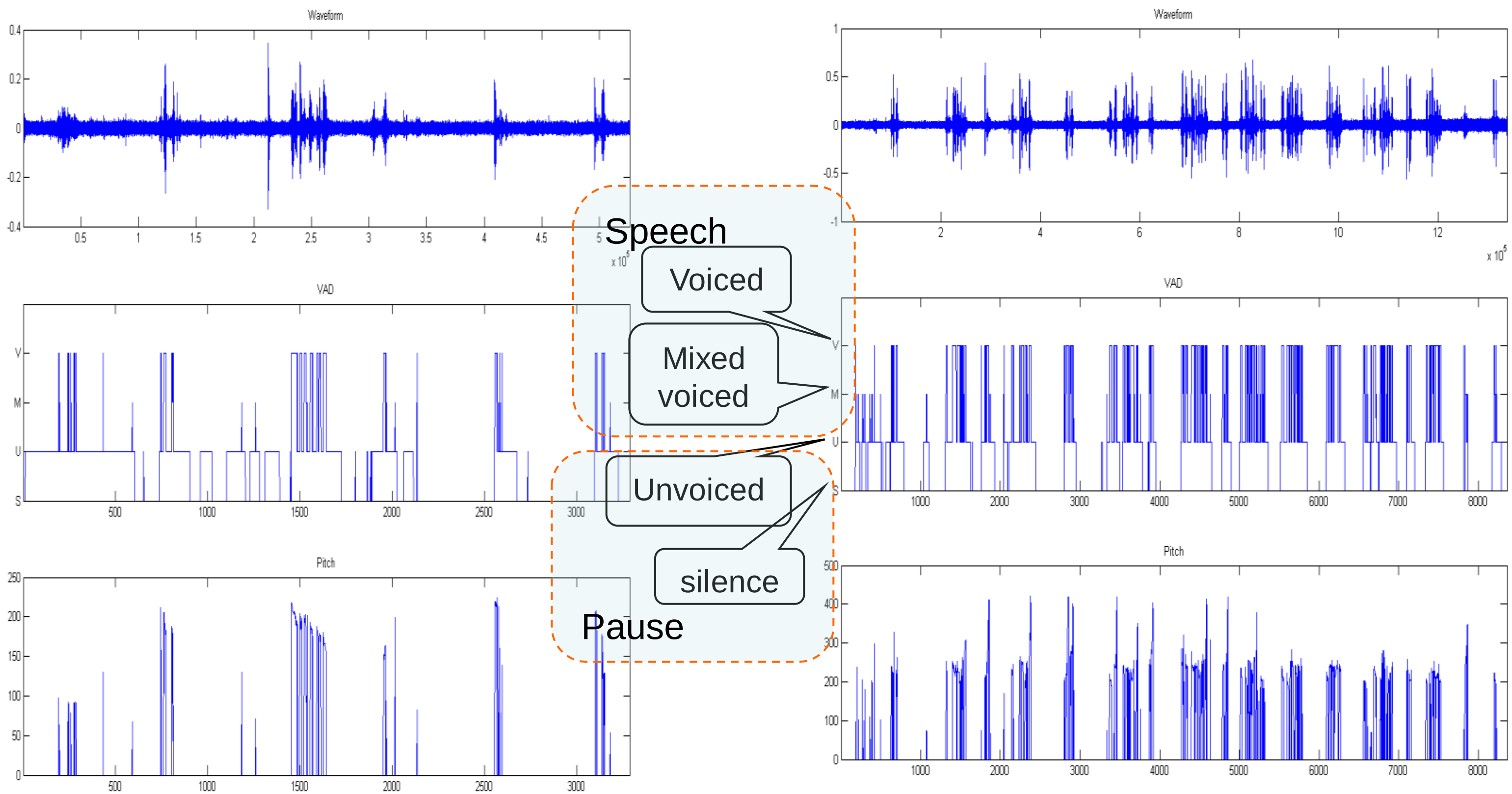
- Disfluencies
  - Interruption rate
  - Proportion of the effective speech in the whole speech period
  - Keywords for correction or repeating
- Inter-sentential pausing
  - Length and frequency of the big pauses
- Fragmented sentences
  - Length and frequency of the small pauses
  - Length of intra-sentence segments
- Slower speech rate
  - Syllable rate
- Response Latency
  - Delay of generating speech
  - Particular hybrid prosodic pattern

Experiment Sp1

- Experimental Setup
  - The task is about handling traffic accidents via voice control
  - The voice control interface is designed as a keyword command system
- Available Data
  - 5 subjects
  - 4 task difficulty levels for each subject
  - 3 sub-tasks for each difficulty level
  - For each subject, the length of all tasks is about 30 minutes, with lots of silence
  - For each action in tasks, the subject only speaks a limited number of individual words

Speech Analysis

- Voice Class and Pitch in Various CL Levels
  - Voice class and pitch (F0) are automatically extracted by a Voice Activity Detector (VAD) and pitch-tracker frame by frame (10ms per frame)



CL Level 1

CL Level 3

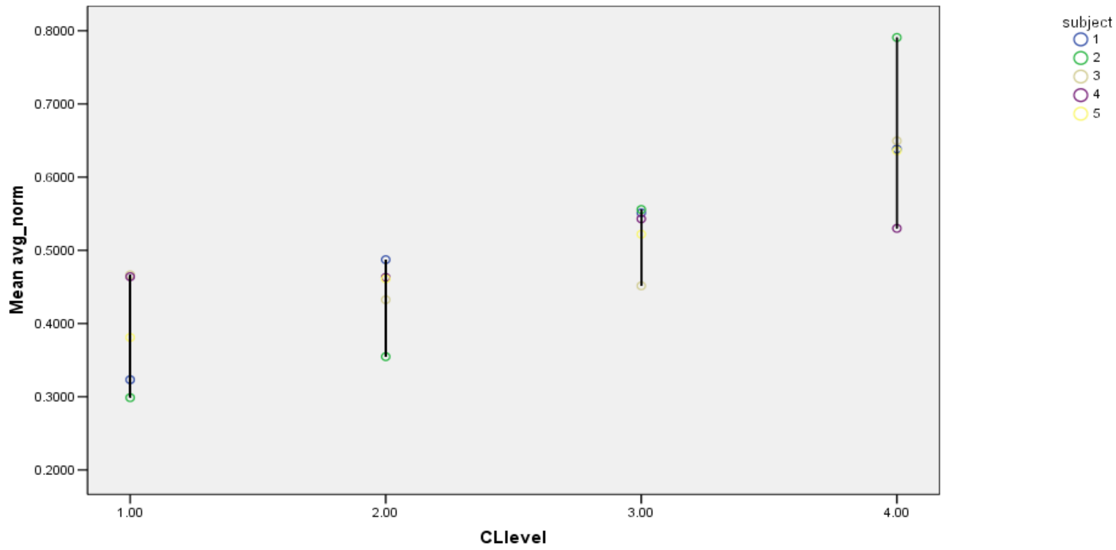
Speech Analysis

- Statistics of Pause-rate

Descriptives

avg_norm

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean: Lower Bound	95% Confidence Interval for Mean: Upper Bound	Minimum	Maximum
1.00	5	.386700	.0776803	.0347397	.290247	.483153	.2988	.4665
2.00	5	.439700	.0512980	.0229411	.376005	.503395	.3548	.4873
3.00	5	.524700	.0429227	.0191956	.471404	.577996	.4515	.5558
4.00	5	.648900	.0929231	.0415565	.533521	.764279	.5300	.7908
Total	20	.500000	.1198338	.0267956	.443916	.556084	.2988	.7908



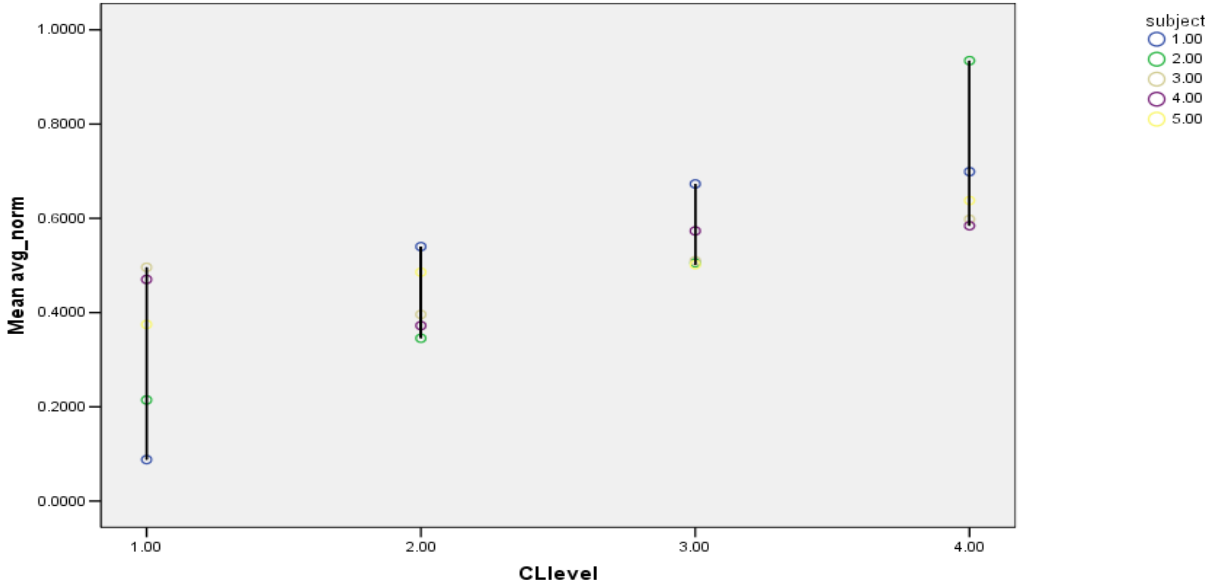
Speech Analysis

- Statistics of the Rate of Pitch Peak

Descriptives

avg_norm

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
1.00	5	.328700	.1740147	.0778217	.112632	.544768	.0880	.4960
2.00	5	.427900	.0818800	.0366178	.326233	.529567	.3455	.5400
3.00	5	.552700	.0733850	.0328188	.461581	.643819	.5018	.6730
4.00	5	.690700	.1433840	.0641233	.512665	.868735	.5843	.9345
Total	20	.500000	.1806638	.0403976	.415447	.584553	.0880	.9345



Experiment Sp2

- A user study with two controlled levels of cognitive load
  - Elicit natural speech from users

- A reading and comprehension task
  - General knowledge (avoid the expertise effect)
  - Reading the extract
  - Answer open-ended questions
    - *Give a short summary of the story in at least five whole sentences.*
    - *What was the most interesting point in this story?.*
    - *Describe at least two other points highlighted in this story.*

The Sun

The Sun has "burned" for more than 4.5 billion years and will continue to do so for several billion more. It is a massive collection of gas, mostly hydrogen and helium. Because it is so massive, it has immense gravity, enough gravitational force to hold all of hydrogen and helium together (and to hold all of the planets in their orbits around the Sun!). The Sun does not "burn" like wood burns – it is a gigantic nuclear reactor….

Experiment Sp2

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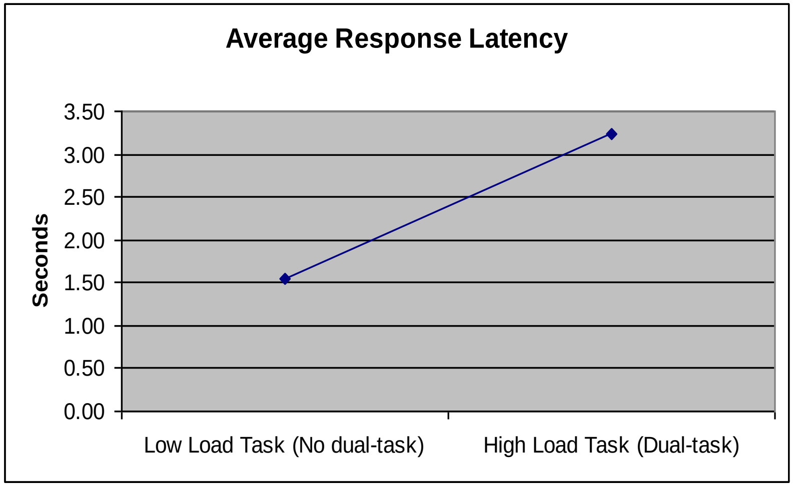
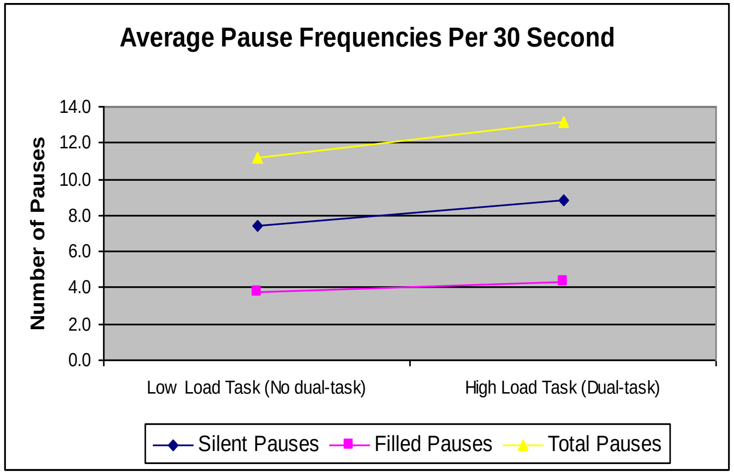
- Cognitive Load Level Design
  - Lexile Framework for Reading (200L 1st grade, 1700L grad)
    - Syntactic and semantic complexity, vocabulary
  - Text with same difficulty for both conditions
  - Aural dual task, counting numbers during reading and answering

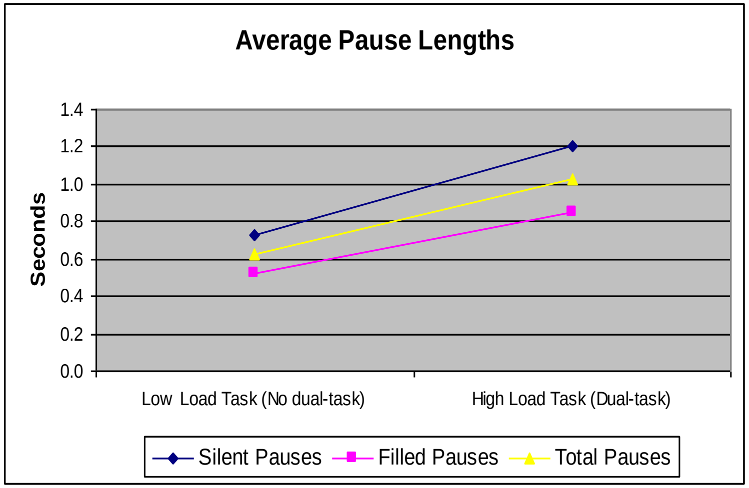
Task Load Level	Lexile Rating	Dual Task
Low	1300L	No
High	1300L	Yes

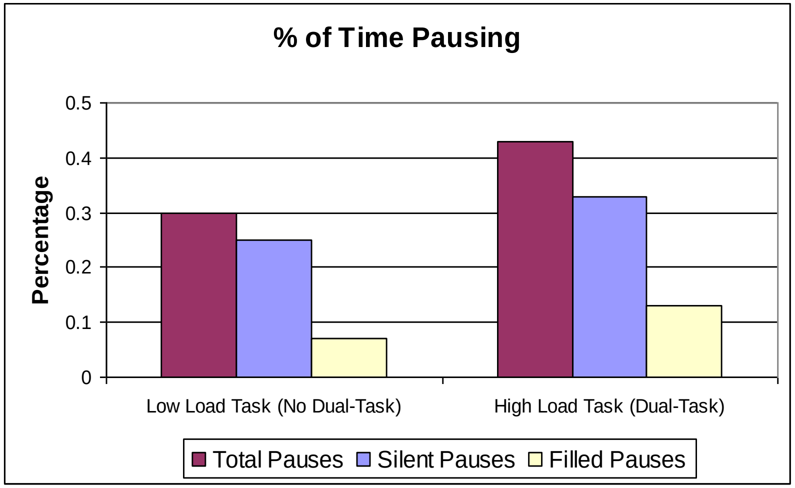
- Participants
  - High Load Condition: with dual-task; 15 subjects (7 male and 8 female)
  - Low Load Condition: without dual-task; 9 subjects (5 male and 4 female).

Pauses and Response Latencies





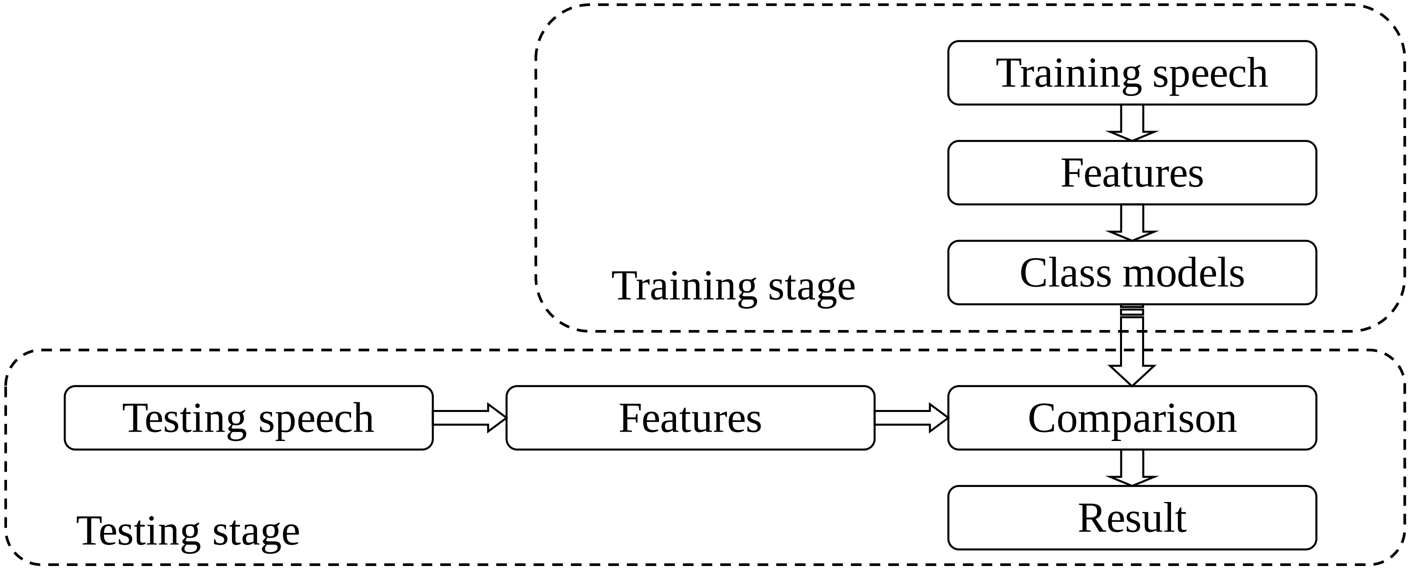




Speech Classification for Automatic CLM

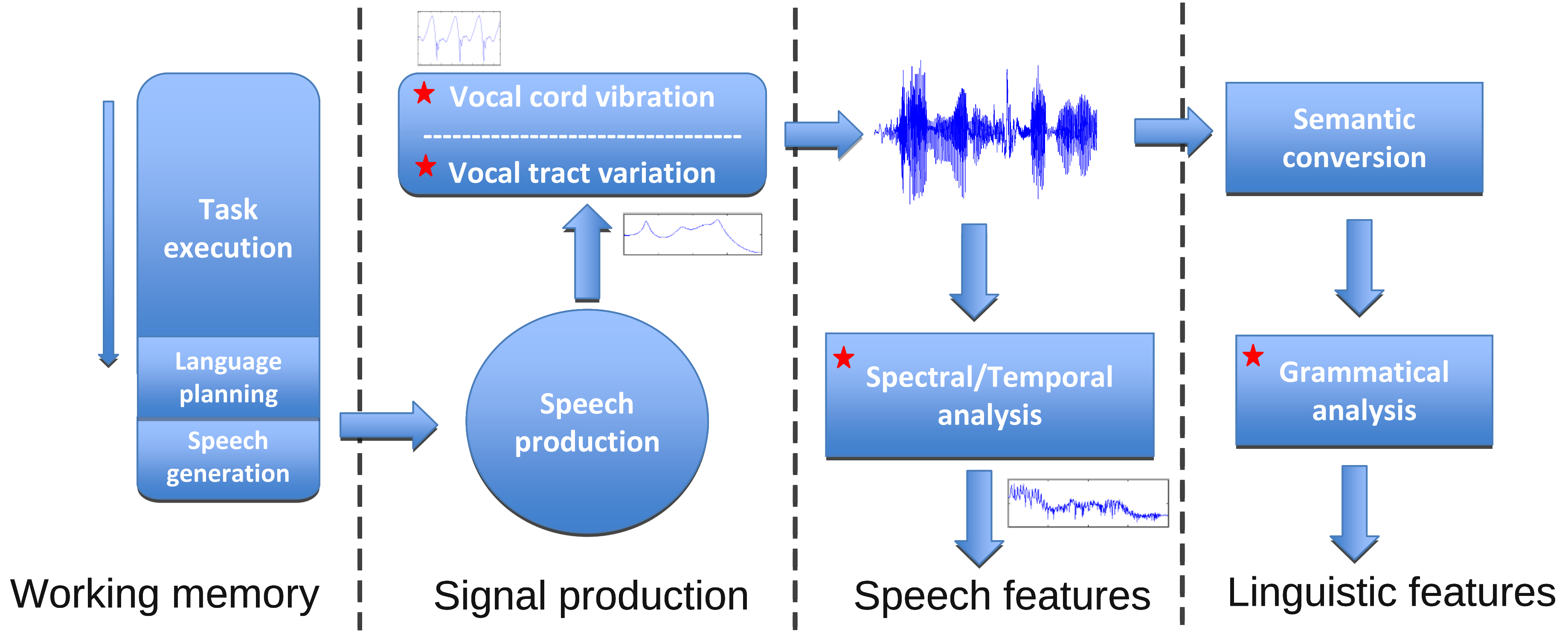
- Measurement -> Classification
  - To take advantage of the statistical modeling power, the original measurement problem is transformed to a classification problem by working on discrete levels

- A typical statistical model-based classification system



Multi-level Speech-based CLM

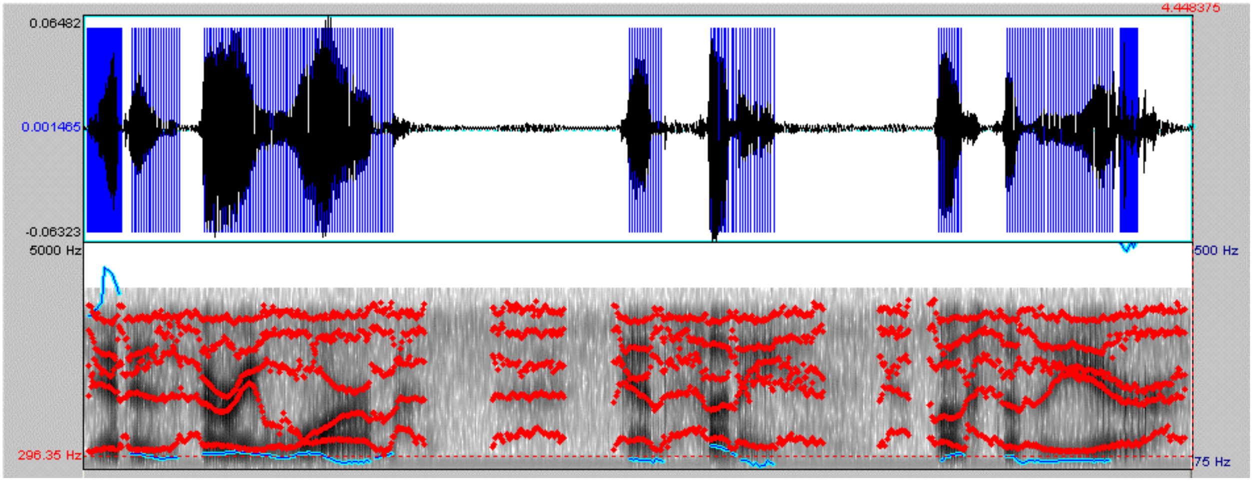
- Acoustic speech features
  - Phase characteristics (signal)
  - Glottal flow (voice source)
  - Formants (vocal tract)
- Linguistic speech features
  - Word categories
  - Pronoun usage
  - Language complexity measures



Baseline Speech Features

- Spectrum features
  - Mel-Frequency Cepstral Coefficients (MFCC)
    - Pre-emphasis -> Spectral analysis -> Mel-scale filterbank -> Log -> Discrete Cosine Transform (DCT)
- Prosodic features
  - Pitch and intensity
    - Track the maximum value of the autocorrelation function

$$\phi(\tau) = \frac{1}{N} \sum_{n=0}^{N-1} x(n)\, x(n+\tau)$$



Exploring Linguistic Features

Linguistic Measures

- **What measures?**
  - Language and word usage
    - Using particular words and/or phrases at specific sentence and/or paragraph positions;
  - Grammar features and structures
    - Using particular types of linguistic/grammatical categories;
    - Using a particular type of syntax or grammatical structure i.e. usage of parts of speech and their forms;

Bushfire Data – Some Hypotheses

- More and longer pauses under high load task.
- More use of:
  - Negative emotions, swear words, perceptive and cognitive phrases, feelings and inclusive words etc.
- Less use of:
  - Positive emotions, complex words, long sentences, etc.
- More disagreements and less agreements
- More hesitations and incomplete sentences
- More use of plural pronouns and less use of singular ones.

Bushfire Data – Linguistic Analysis

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- **Linguistic word categories:**
  - **WC:** Total number of words used by the user.
  - **WPS:** Number of words used per sentence.
  - **LW:** Number of long words, i.e. words with at least six letters
  - **AW:** Prepositions and Conjunction words, e.g. about, along, although, because, etc.
  - **NE:** Words that denote negative emotions, e.g. annoy, angry, messy, sorry, stupid etc.
  - **Cog:** Words that represent the human cognitive processes, i.e. think, consider, etc.
  - **Inc:** Inclusive words, e.g. and, both, each, including, plus, with etc.
  - **Per:** Perception words, e.g. vision, beauty, quite, rough, cold, etc.
  - **Feel:** Words that denote feelings, e.g. hard, difficult, heavy, loose, sharp, tight, wet etc.

Table 1. Significant Linguistic Features.

Features→ / ↓Data Sets	WPS	AW	NE	Per	Cog	Feel
Load-wise (All Roles)	+24%	-22%	+42%	+21%	+14%	+62%
Role-wise (IC)	+39%	-15%	+98%	+36%	+18%	+113%
Role-wise (Planning)	+22%	-48%	+80%	+20%	+4%	+20%
Role-wise (Operations)	+14%	-2%	+9%	+8%	+13%	+26%

Shaded cells = Statistically significant; $p < 0.03$

+ increasing trend, – decreasing trend

Table 2. Supporting Features

Features→ / ↓Data Sets	WC	LW	Inc
Load-wise (All Roles)	+12%	+5%	+4%
Role-wise (IC)	+4%	+13%	+5%
Role-wise (Planning)	+5%	+2%	+4%
Role-wise (Operations)	+7%	+5%	+11%

Bushfire Data – Linguistic Analysis

NICTA

- Pronoun usage and agreement
  - Singular decrease
  - Plural increase

		Task Difficulty/ Load Levels				p-value
		1	2	3	4	
Singular Pronouns	I	3.12	1.77	1.68	0.95	0.001
	she/he	1.44	0.57	0.48	0.27	0.002
Plural Pronouns	we	2.21	3.19	3.78	4.73	0.01
	they	0.49	1.18	1.30	1.90	0.02

Table 1. Pronoun types vs. Cognitive load levels. The values under load levels are mean percentages of total words for four pronoun types

  - Agreements decrease
  - Disagreements increase

	Task Difficulty/ Load Levels				p-value
	1	2	3	4	
Agreement	3.10	2.66	2.05	1.61	0.03
Disagreement	1.16	1.29	1.57	2.22	0.002

Table 2. Agreements vs. Cognitive load levels

Bushfire Data – Linguistic Analysis

- **Language complexity measures**
- Measured by two major factors:
  - **Semantic difficulty**: observes the use of words, their frequencies, and their lengths (both in syllables as well as alphabets/characters).
  - **Syntactic complexity**: observes primarily the sentence length, which is considered as the best indicator of text or language complexity.

Complexity Measures	Sentence Length	No of Words	Syllables	Complex Words	Full Comprehension
Lexical Density		✓			
Complex Word Ratio		✓	✓	✓	
Gunning Fog Index	✓	✓	✓	✓	
Flesch-Kincaid Grade	✓	✓	✓		
SMOG Grade	✓		✓	✓	✓
Lexile Level	✓	✓			

  - **Complexity increases**
  - **Lexical Density decreases**

Measure	Low Load	High Load	Difference	p-value
Lexical Density	67.3	64.2	–4.8%	0.04
Complex Word Ratio	0.052	0.061	+17%	0.0001
Gunning Fog Index	5.78	7.08	+22.5%	0.0001
Flesch-Kincaid Grade	2.79	3.96	+42%	0.0004
SMOG Grade	6.76	7.51	+11%	0.0003
Lexile Level	712	905	+27%	0.0004

Table 1. Summary of Complexity Measures under Low vs. High Cognitive Load Tasks; Differences significant for $p<0.05$.

Fire Management Lab Experiment

- Collaborative task using TouchTable.
- 10 groups x 4 members = 40 subjects
  - 30 Commanders + 10 Leaders
  - 39 subjects data available (1 leader's data missing)
- Speech Transcriptions completed in ELAN format.
- Analysis completed, results are available:
  - Subjective Ratings
  - Pronouns
  - Word Category Features
  - Language Complexity

Results: Subjective Ratings

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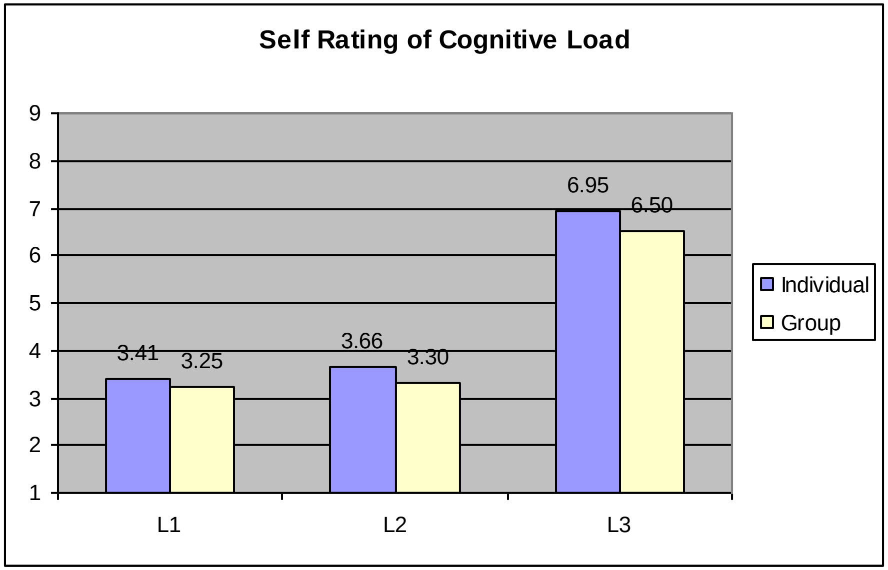


- ANOVA, significant for $p<0.05$

Difficulty/Load	L1	L2	L3	p
Individual	3.41	3.66	6.95	0.0000
Group	3.25	3.30	6.50	0.0000

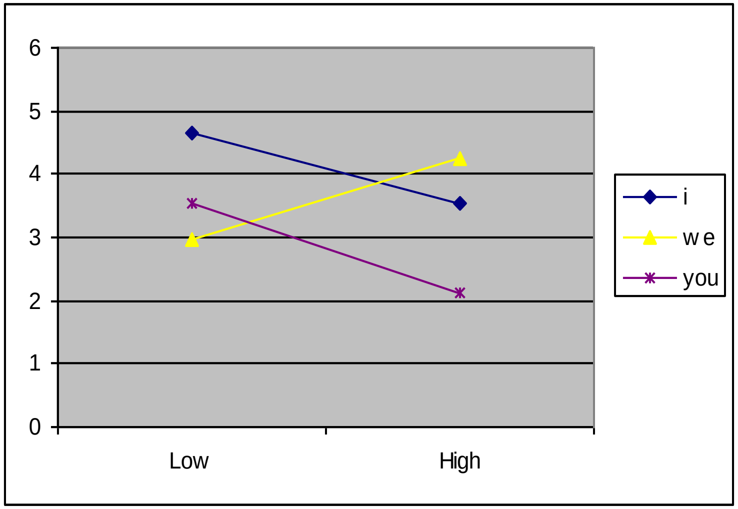
- t-Test, significant for $p<0.05$

Difficulty/Load	Low	High	Diff %	p
Individual	3.53	6.95	96.9%	0.0000
Group	3.27	6.50	98.8%	0.0000

Results: Pronouns

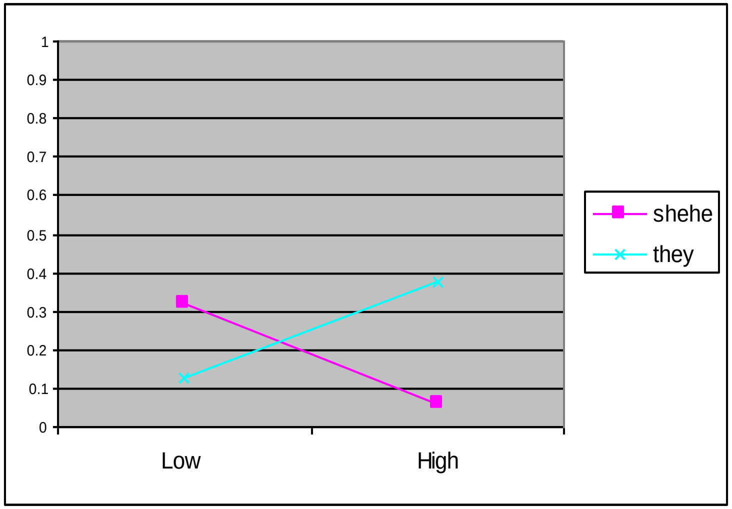
- Dependent Means Paired t-Test; $p<0.05$

	Pronoun	Low	High	Difference	p
Singular	i	4.668333	3.52359	-25%	0.000983
	shehe	0.323077	0.058718	-82%	0.016312
Plural	we	2.955128	4.233846	43%	0.000040
	they	0.128077	0.377949	195%	0.027002
?	you	3.548462	2.113846	-40%	0.000114



- Group Averages

	Pronoun	Low	High	Difference	p
Singular	i	4.616917	3.515833	-24%	0.034162
	shehe	0.315	0.05725	-82%	0.02969
Plural	we	2.923958	4.245167	45%	0.001171
	they	0.124875	4.245167	300%	0.000015
?	you	3.584792	2.109917	-41%	0.000517



Results: Word Category Features

- Dependent Means Paired t-Test; p<0.05
- All subjects combined

Feature	Low	High	Diff. %	p
WC	179.20513	322.3846	79.90%	0.000000
WPS	4.7287179	6.12641	29.56%	0.000000
LW	10.045	11.16744	11.17%	0.010884
PE	5.7374359	3.816923	-33.47%	0.000006
Cog	12.176282	14.16513	16.33%	0.00066
Percept	2.3328205	3.251282	39.37%	0.002222
Feel	2.0210256	2.747692	35.96%	0.00716
AW	8.3403846	6.772564	-18.80%	0.001417
Incl	4.5896154	5.633077	22.74%	0.003247
Agree	7.3533333	5.259744	-28.47%	0.000322
Disagree	2.0671795	2.607949	26.16%	0.04693
tentative	1.4274359	1.737949	21.75%	0.104407
certain	0.4225641	0.417436	-1.21%	0.963104
NE	2.5246154	2.95641	17.10%	0.156248
swear	0.2452564	0.394615	60.90%	0.116099
achieve	1.4594872	1.133333	-22.35%	0.174984

- Group averages

Feature	Low	High	Diff. %	p
WC	178.02917	322.5583	81.18%	0.000006
WPS	4.7025833	6.111833	29.97%	0.000104
LW	9.9977917	11.15717	11.60%	0.052639
PE	5.7249583	3.832417	-33.06%	0.000841
Cog	12.129375	14.12717	16.47%	0.000807
Percept	2.32175	3.27425	41.03%	0.013577
Feel	2.0145	2.776083	37.81%	0.008585
AW	8.335625	6.842917	-17.91%	0.027287
Incl	4.5595833	5.639	23.67%	0.006942
Agree	7.4460833	5.363417	-27.97%	0.003938
Disagree	2.1547917	2.583667	19.90%	0.253849
tentative	1.419625	1.720333	21.18%	0.072956
certain	0.4257917	0.418	-1.83%	0.937023
NE	2.5301667	3.0115	19.02%	0.241955
swear	0.239125	0.403667	68.81%	0.167324
achieve	1.455	1.127917	-22.48%	0.327861

Language Complexity Measures

- Dependent Means Paired t-Test; $p<0.05$

- All subjects combined

Feature	Low	High	Diff. %	p
Lexical Density %	44.86128	32.94256	-26.57%	0.000000
Lexical Density Sampled	53.72679	48.9959	-8.81%	0.000047
Complex Words Sampled	4.128205	5.153846	24.84%	0.001933
Complex Word Ratio	0.080047	0.088346	10.37%	0.024017
Gunning Fog Index	4.946667	5.731538	15.87%	0.000003
Flesch-Kincaid Grade	0.790256	1.391282	76.05%	0.000004
SMOG Grade	6.11141	6.723077	10.01%	0.000000
Lexile Level	966.0256	1074.615	11.24%	0.040432

- Group averages

Feature	Low	High	Diff. %	p
Lexical Density %	44.84529	32.80858	-26.84%	0.000006
Lexical Density Sampled	53.62221	48.88183	-8.84%	0.000076
Complex Words Sampled	4.091667	5.15	25.87%	0.033549
Complex Word Ratio	0.079898	0.088423	10.67%	0.028544
Gunning Fog Index	5.016625	5.77225	15.06%	0.001852
Flesch-Kincaid Grade	0.775417	1.379833	77.95%	0.000577
SMOG Grade	6.103875	6.7215	10.12%	0.000277
Lexile Level	969	1072.167	10.65%	0.04277

Exploring Pen Input

Pen Input Features

- High cognitive load can be reflected in communicative signals (production)

- Symptoms of cognitive load,
  - depending on the application (e.g. blackberry, tablet etc)
  - Geometric and temporal features (shape and trajectory)
  - Interactive features (when it is used and for what)
  - Content analysis (what is being drawn)

Traffic Incident Study: Design

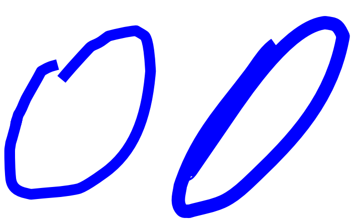
- Creating traffic detours and green light corridors
  - Using pen and speech interaction on a tablet
  - Scratchpad for 'working out'
- Subjective ratings (1-9 scale) and performance scores

<u>Cognitive Load Levels</u>

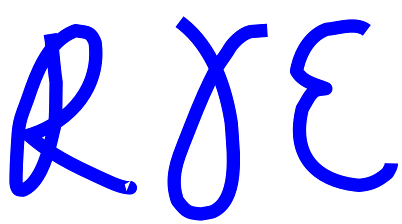
Low (Easy): 6 streets

Medium (Med): 10 streets

High (Hard): 16 streets



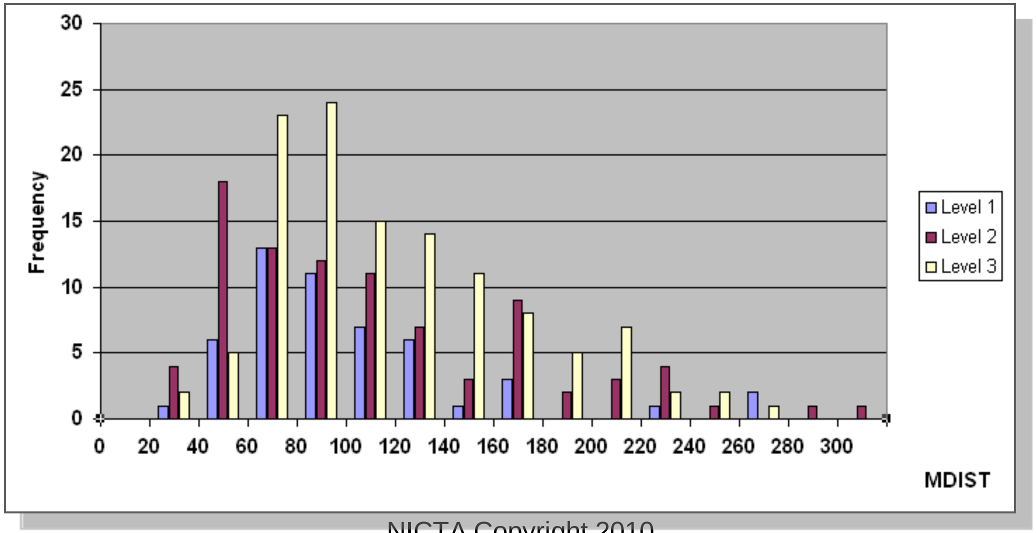
Selection Examples



Shape Examples

Degeneration of Interactive Shapes

- **Geometric analysis of trajectory**
  - 12 features from Rubine[1991] paper on single stroke pen-gesture recognition e.g. angle at start stroke, angle and end stroke, duration, length, sharpness etc
- **Malahanobis distance (MDIST-** a weighted Euclidean distance)
  - The number of standard deviations a pen-gesture is away from the mean of its "standard/baseline" form, captured during training.
  - As load increases, the curve moves away from 0, indicating a greater degree of degeneration (statistically significant).

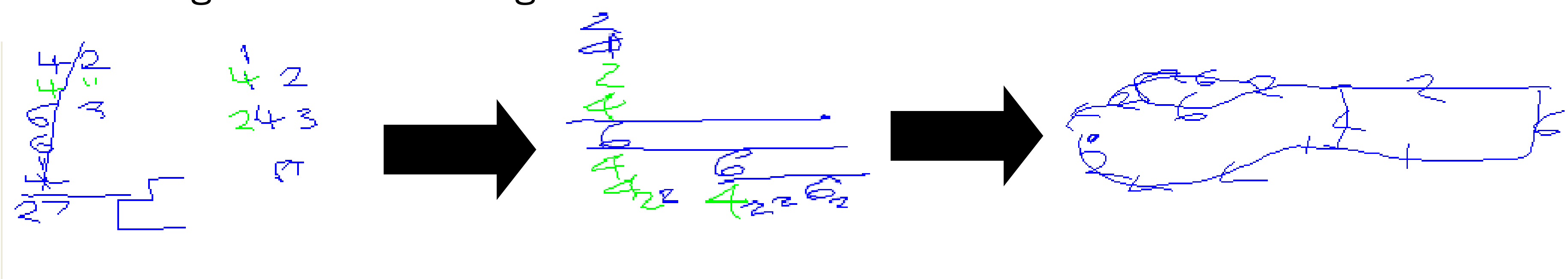


Use of the Scratchpad

- Scratchpad as a cognitive tool
  - Use of note-taking as an external memory aid
    - High usage expected during high cognitive load
  - Organisational marks for understanding, clarification, planning.
  - Diagramming as a strategy for generating and discarding hypotheses
  - Content Analysis:

    Alphanumeric -> Symbolic, Organisational -> Diagrammatic

- Results
  - Significantly increased usage ad CL increases (manual freq)
  - Automated trajectory frequency count and rate per second significantly increasing
  - Use of diagramming doubles between low load tasks and high load tasks (manual freq)
  - Increased evidence of symbolic and organisational marks, as well as spatial representations when cognitive load is high



Basketball User Study Design

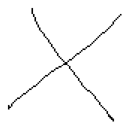
- Recalling basketball player formations from 10s video clip
  - Mark the position of the players on the court
- Subjective ratings (1-9 scale) and performance scores
- Longitudinal: Pre-Test, 6 Training Sessions, Post-Test

Cognitive Load Levels

Low (Easy): 3 players

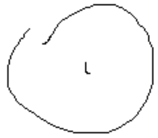
Medium (Med): 6 players

High (Hard): 10 players



Attacker

Defender



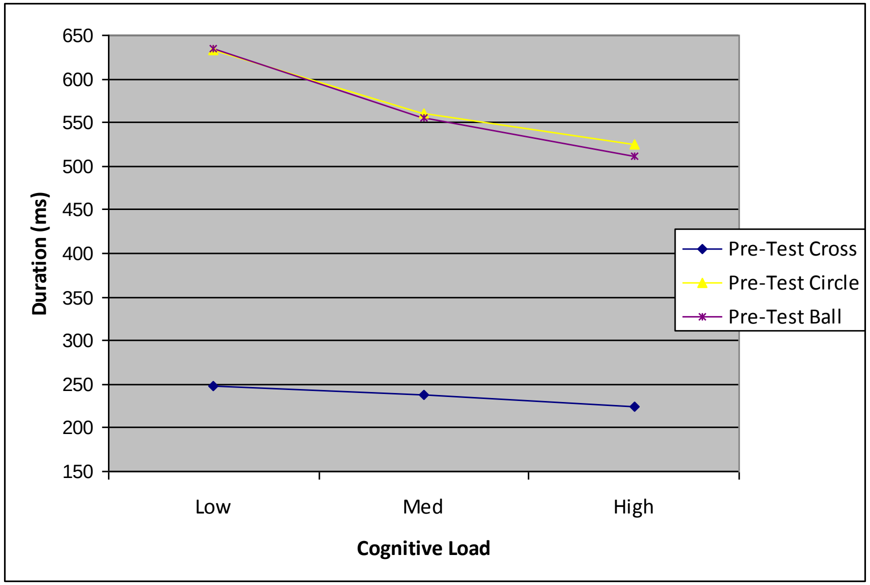
Ball Carrier

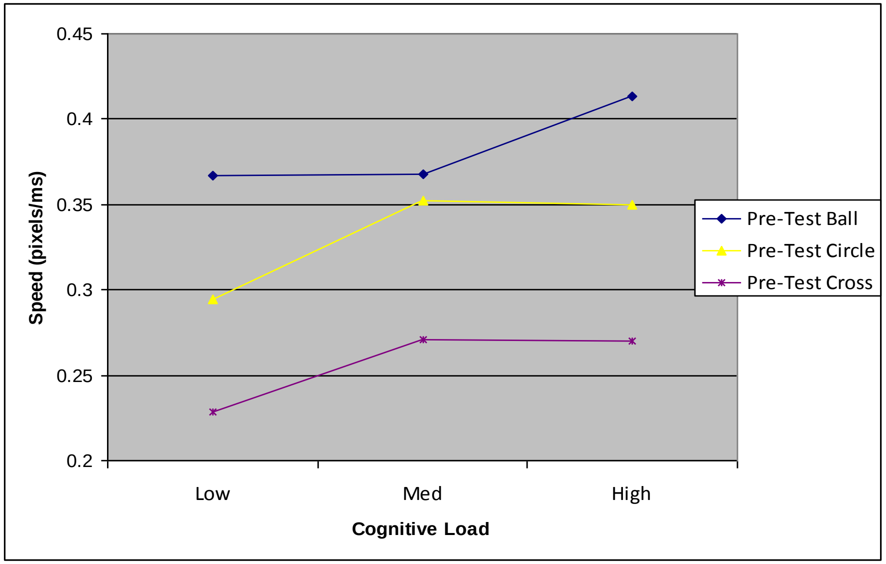
Basketball User Study

Pen-Input Results – Trajectory Durations

- Circles and Cross shapes

- Trajectory analysis
  - Significant trends of decrease in trajectory duration as CL ↑
  - Significant trends of decrease in trajectory velocity as CL ↑,
    - Except in Ball Carrier





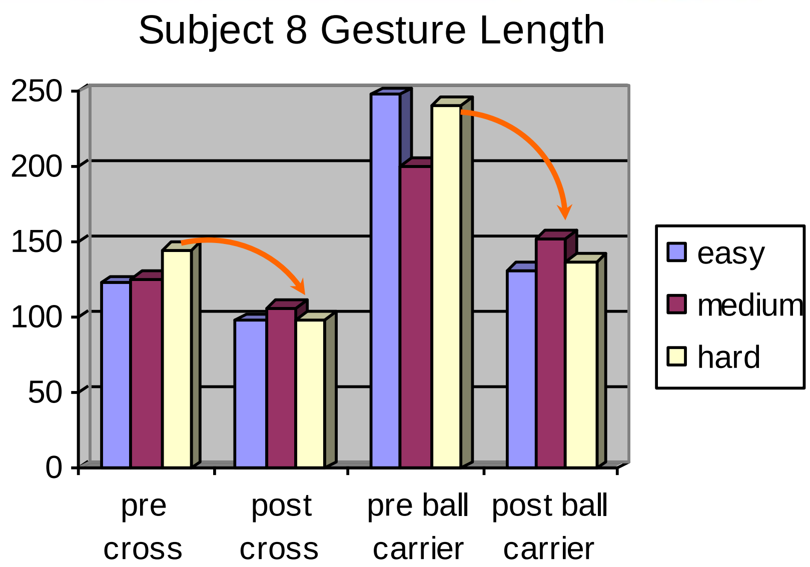
Feature Analysis: Length

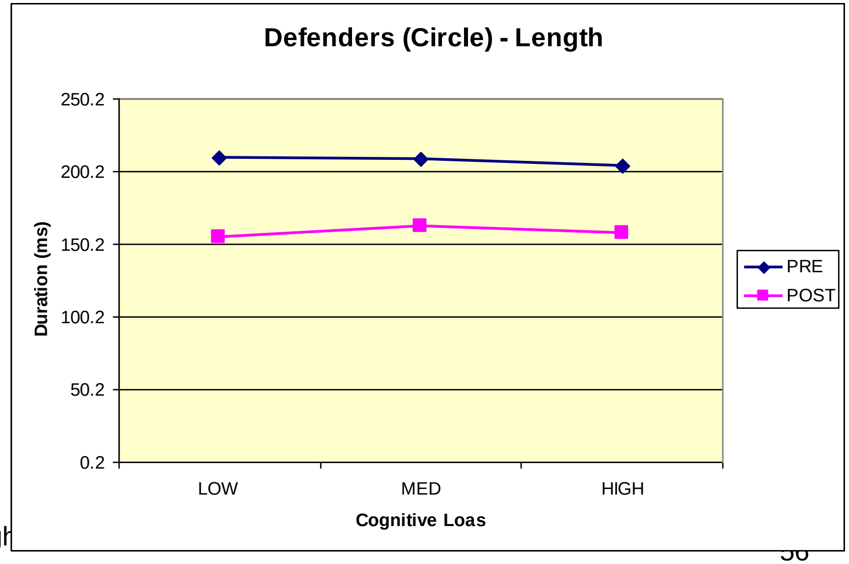
- Changes from Pre-test to Post-test

Hypothesis: Gesture length will change as subjects master the task.

Gesture length (related to gesture duration) decreased from pre-test to post-test.

Repeated measures ANOVA shows significant effect of expertise (decreasing length from pre to post).

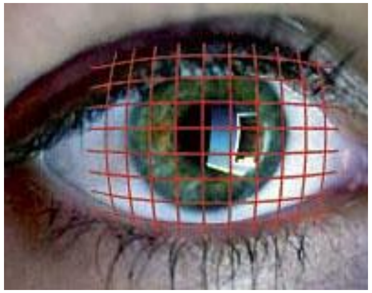




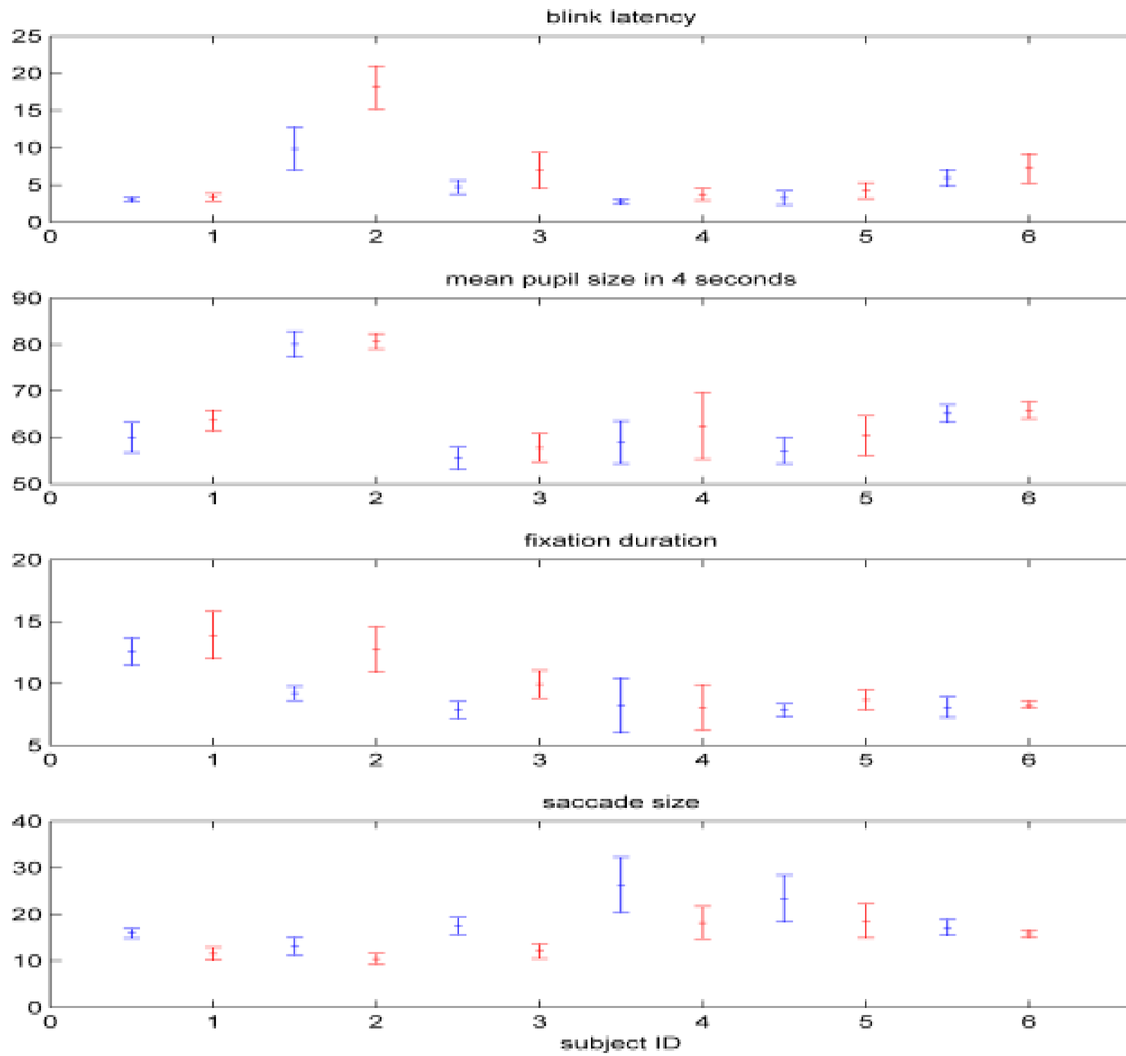
Exploring Eye Movement

Eye Activity Results

- Video-based measure

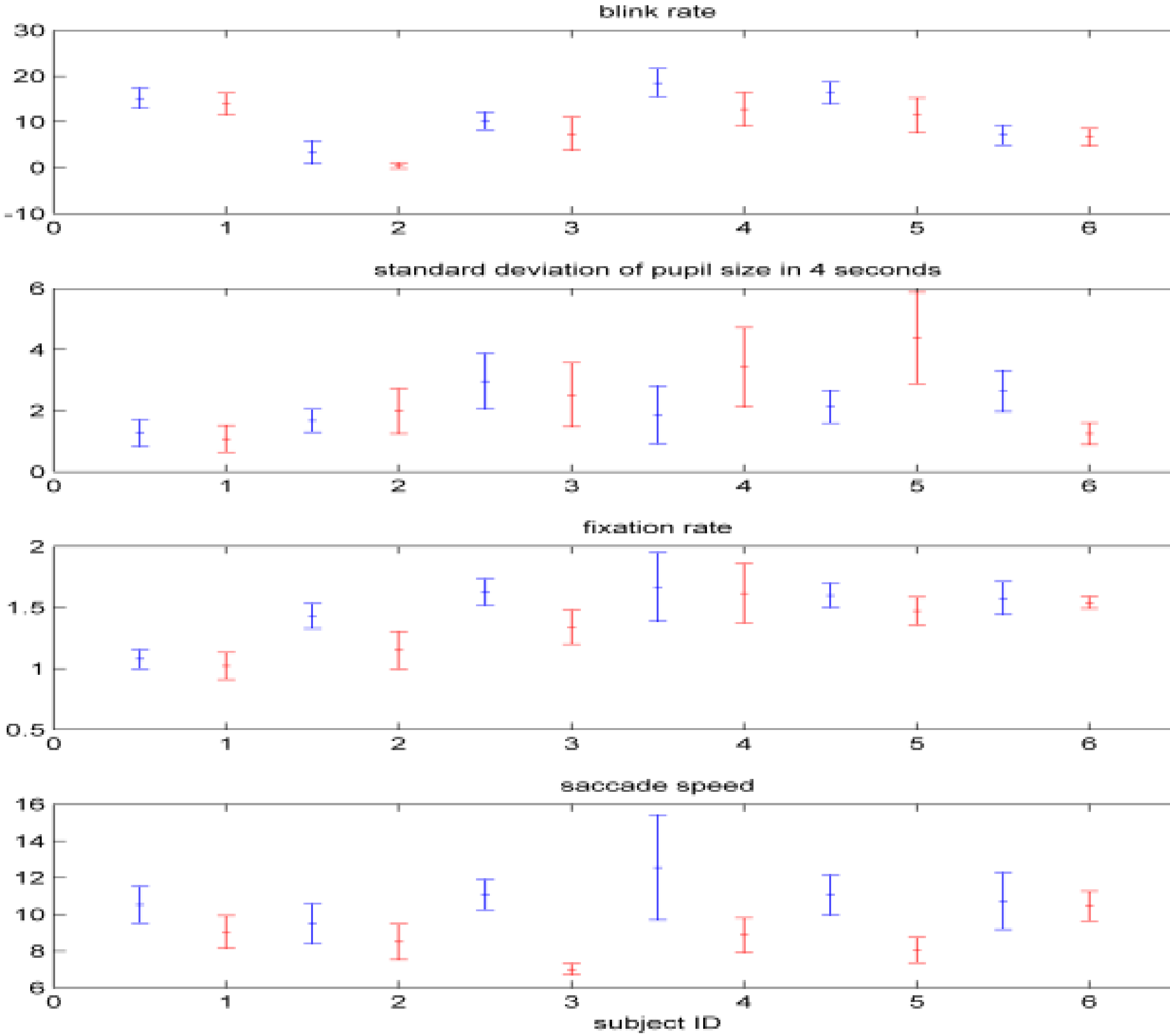


- Low to Medium load
- As cognitive load increases,
  - Blink latency ↑
  - Mean pupil size ↑
  - Fixation duration ↑
  - Saccade size ↓
  - All significantly



Eye Activity Results (2)

- As cognitive load increases,
  - Blink rate ↓
  - Fixation rate ↓
  - Saccade speed ↓
  - All significantly



Exploring Multimodality

Experiment

- Hypothesis:
  - Users are more likely to use complementary multimodal productions as cognitive load increases
  - Users will tend to rely on one modality more as cognitive load increases

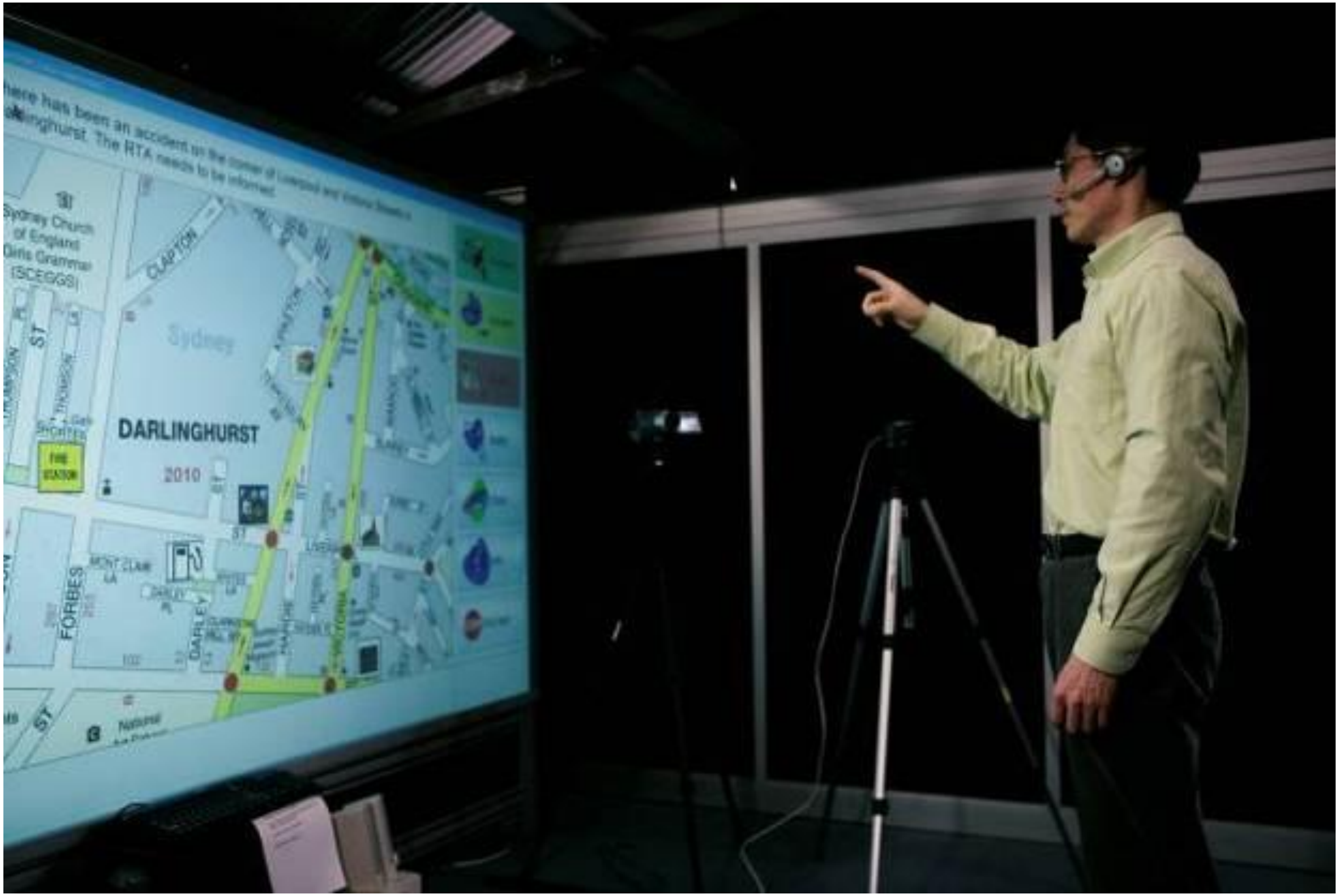
- Method:
  - Wizard of OZ scenario:
    - speech and gesture interface for a series of map based tasks;
    - task increasing in difficulty by varying quantity of content and time-pressure
  - Conditions for Speech Only interaction, Gesture Only interaction and Multimodal
  - Videotape participants, record audio, record answers, post-hoc introspection questionnaire

Experiment Design

- Task:
  - Incident Management Response
    E.g. A major accident on corner of X and Y.
  - Operators are required to deploy necessary crews and implement policies and procedures

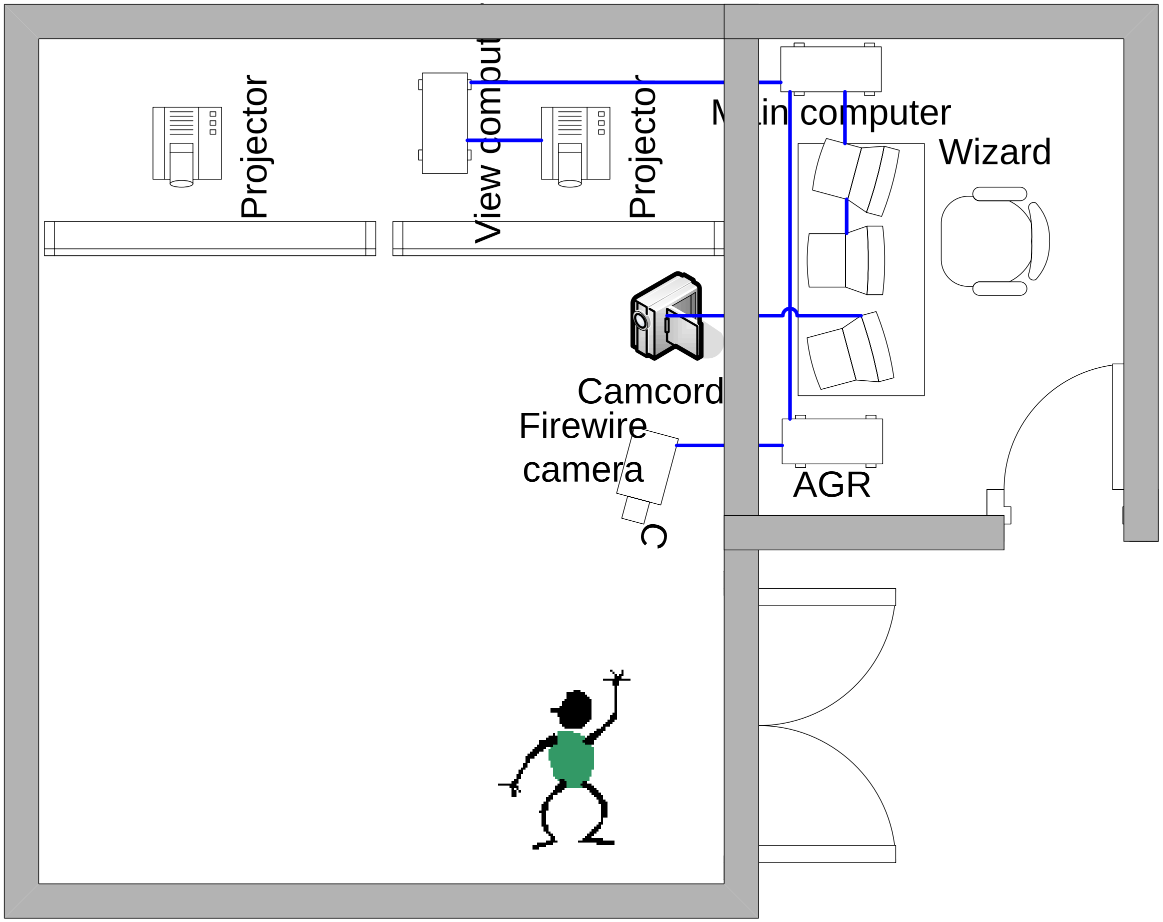
- Dependant Variables:
  - Biosensor input: GSR and BVP
  - Gesture: video footage
  - Speech: transcribed manually
  - Performance: latency, completion time & error-rates
  - Multimodal productions: manual annotation

Experimental Setup



Wizard of Oz

DEMO



Task Difficulty Level Design

NICTA

- There were four levels of cognitive load, and three tasks were completed for each level.
- The same visual was used for each level to avoid differences in visual complexity.
- The tasks varied in load through:
  - The number of distinct entities in the task description;
  - The number of distractors (items not needed for the task);
  - The minimum number of actions required for the task.
  - Further load was achieved in Level 4 by introducing a time limit.

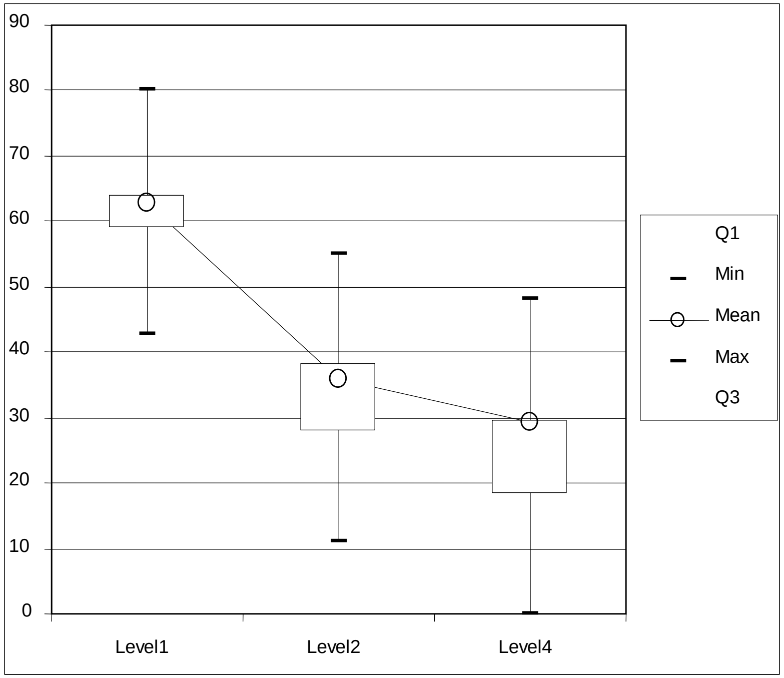
Level	Entities	Actions	Distractors	Time
1	6	3	2	∞
2	10	8	2	∞
3	12	13	4	∞
4	12	13	4	90 sec.

Results: Rates of Redundancy

NICTA

- Redundancy:
  - Conveying the same information over more than one modality,
  - Either would be sufficient on its own

Turn	Const	Modality	Content
Pure Redundant	Select	Gesture	[point to St Mary's Church]
		Speech	"Select St.Mary's Church"
	Tag	Hand_Shape	[scissors=Incident]
		Speech	"Incident"



Proportion of Purely Redundant turns by Level

- We found a statistically significant **decrease** in the number of purely redundant turns from
  - 62.91% in Level 1 to
  - 29.9% in Level 4 of all multimodal turns.

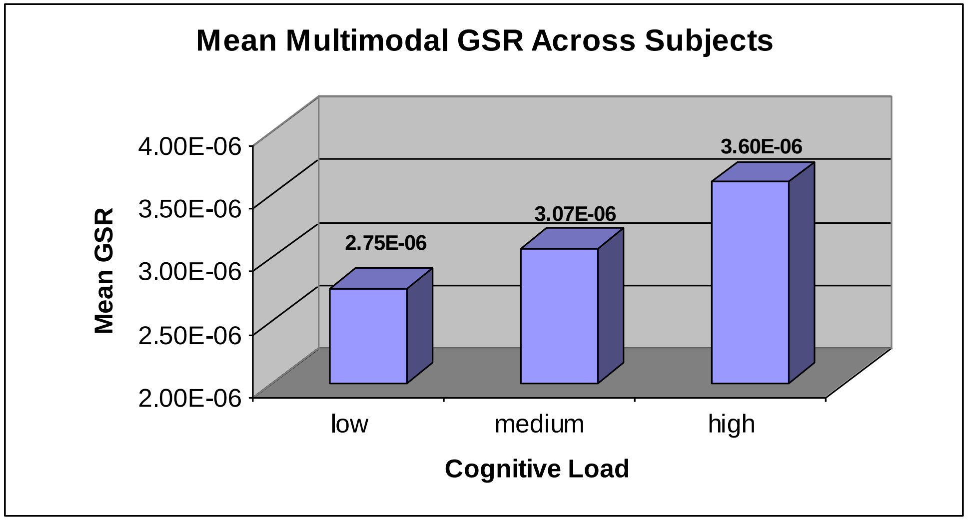
Physiological Signals

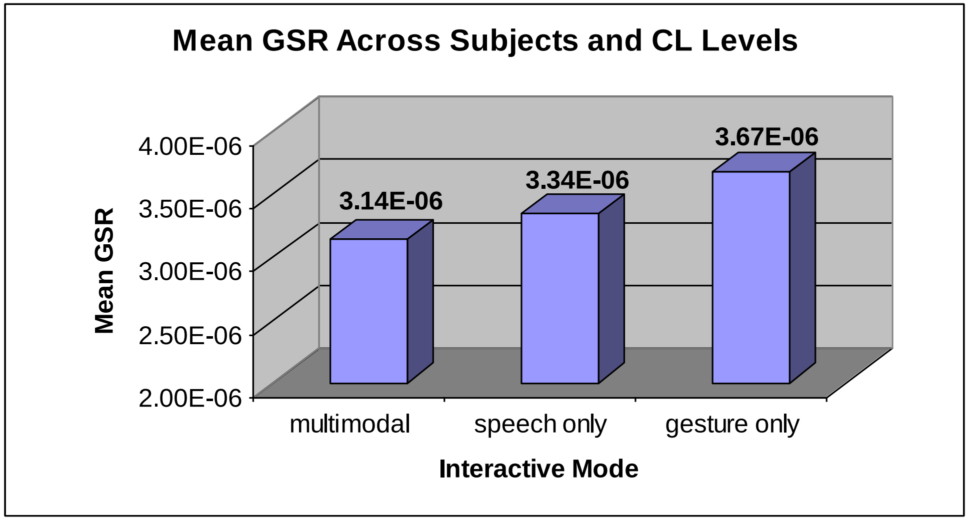

Urgent: Traffic lights are down on the entire Brisbane Avenue, East of Capital Hill, in Barton. Accident at corner of Young street. RTA with traffic light engineer required.
PARKES
CAPITAL
BARTON
2600
2600
KINGS
BRISBANE
BLACKALL
Charles Sturt University
Canberra Campus
Accident
Incident
Info
End task


ProComp


Canon

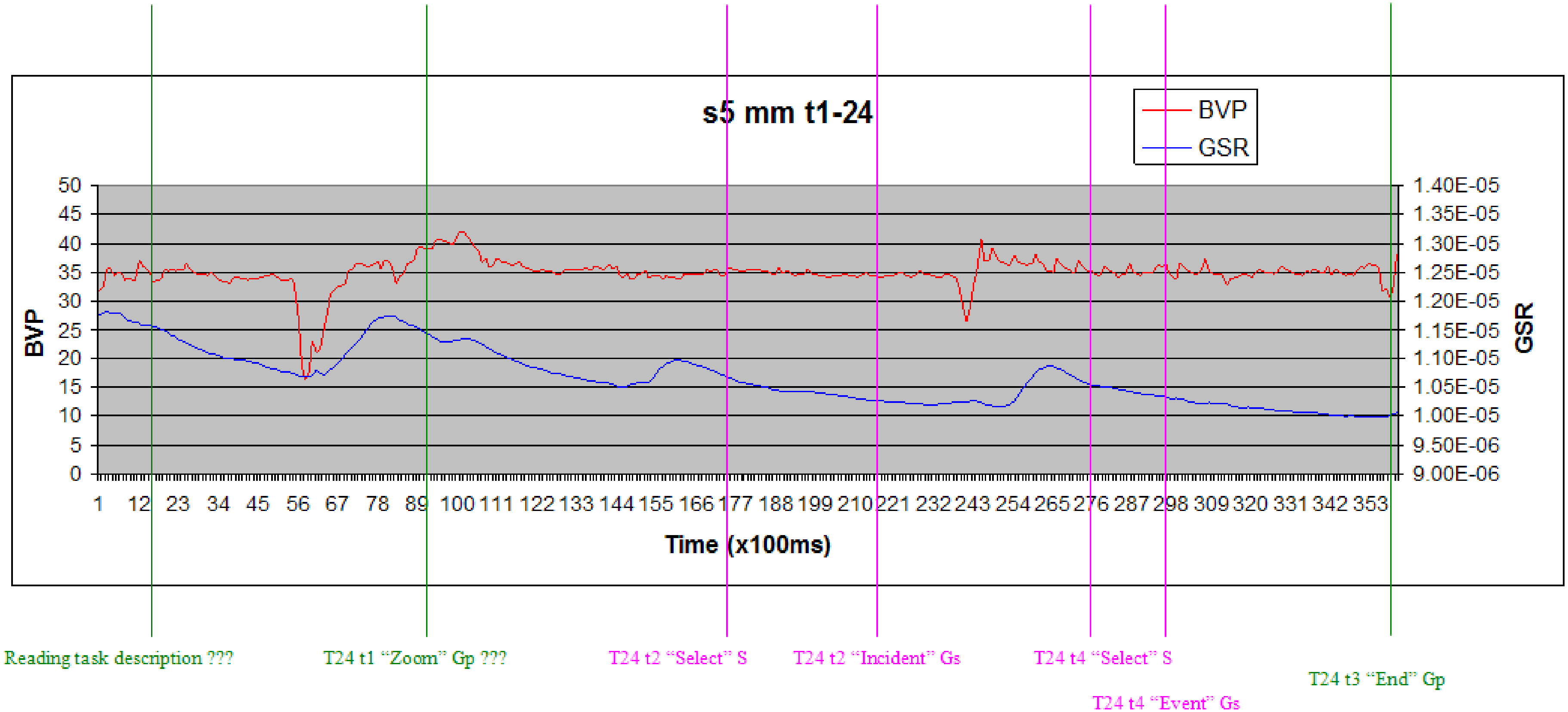
Mean GSR against CL and Modality





Correlation

- Correlation between GSR and “multimodal turns” within each task.



Summary: Technology Focus

What modality to measure?

- Pen Gesture
- Eye Movement
- Speech/Linguistics
- GSR
- EEG
- ……….

What mental state to measure?

- Stress
- Emotion
- Cognitive Load
- Arousal
- Attention

What entity to measure?

- Task
- Human
- System

What can be done with the measurement?

- Adaptive User Interfaces
- Cognitive Analytics
- Task Complexity Analysis
- Performance Prediction
- Performance Monitoring
- Usability Evaluation
- ……….

Summary

- Cognitive load can be determined through Multimodal Behaviours
  - Implicitly and unobtrusively
  - Monitoring variations of specific multimodal features
  - Assessing users' cognitive load through their multimodal behaviours requires identifying a **number of indices** that reliably reflect load fluctuations.

- The ability to implicitly measure the perceived level of cognitive load means that:
  - Applications could adapt the information output flow
  - In a very user-centric way
  - Thus achieving optimal information delivery and maintaining CL

Long Way to Go

- User-dependent measurement (relative to their baseline behaviour)
- Significant semantic changes in multimodal constructions
- Correlation between physiological sensor data variation and interactive behaviour
- Multimodal and multiple-type classifiers (fusion)
- Application independent measurement
- Real-time dynamic measurement
- ...

Better Performance, Better Interface, Better Evaluation!

Call for Collaborations

- Accurate real-time cognitive load (mental load) measurement
- Adaptive Interfaces
- Research into “mental space”
  - All mental states exist in some kind of ‘mental state space’
  - Carefully designed experiments can theoretically isolate one mental state dimension or axis
    - e.g. ‘cognitive load’
    - e.g. ‘affect’ and ‘arousal’
  - Axes are interesting
    - e.g. is ‘cognitive load’ correlated with ‘stress’ ?
- Collaborative Interfaces
  - How team behaviours change under different levels of load
- …

Thank You

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