Mental Workload

The portion of operator’s limited mental capacities actually required to perform a particular task

Why measure it?
- Performance limits
- Predict top performance and operation failure

Tasks
- Cognitive/perceptual
- Multiple/simultaneous

High mental workload
- Air traffic controller, pilot, military command & control, nuclear power plant operator, anesthesiologist

But what about
- Computer programmer, university professor, teacher, mathematician, PhD student?

High Mental Workload

Stimulus driven not self paced
- Large fluctuations in demand
- Multiple simultaneous tasks
- High stress/high consequence

Yerkes-Dobson law
- Low arousal → Low performance
- Moderate arousal → High perf.
- Over arousal → Low perf.

Index (measure) of Mental Workload

Sensitivity: index must be sensitive to changes in task difficulty or resource demand
- Selectivity: index should NOT be sensitive to changes unrelated to resource demands
- Diagnosticity: index should indicate not just that workload is varying but the cause of variation
- Obtrusiveness: an index should not interfere with or contaminate the primary task being assessed
- Reliability: index should produce the same estimate for a given task and operator
- Bandwidth: the index should respond to high-frequency (quick) changes in workload
- Implementation requirements and operator acceptance

Measures of Mental Workload
Primary & Secondary Task Measurements

- **Primary task measurement**
  - Measures the performance outcome as a function of primary task demand (how well are you driving?)

- **Secondary task measurement**
  - Emphasize performance on the primary task
  - Operator allocates as much resource capacity as needed to the primary task
  - Impose secondary task to measure residual resources or capacity not utilized in the primary task
  - Secondary task performance should thus be inversely related to the primary-task resource demands
  - Shows changes in resources demanded by the primary task when there is reserve capacity

Secondary task measurement

- Maximum Capacity (Without Impaired Performance)
- Early Selection
- Late Selection
- Single Resource
- Multiple Resources

<table>
<thead>
<tr>
<th>Performance Level</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
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<tbody>
<tr>
<td>Easy (E)</td>
<td>P</td>
<td>P</td>
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<td>Moderate (M)</td>
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<td>Difficult (D)</td>
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Primary Task Demand (PTD)

Physiological Measures

- Heart rate (ECG)
- Blood pressure
- Respiratory rate variability
- Tidal volume
- Ventilation
- Galvanic skin response
- Evoked response amplitude
- Evoked response latency
- Electroencephalogram (EEG)
- Spectral components
- Time domain
- Flicker fusion frequency
- Pupil diameter
- Electromyograms (muscles)
- Electrooculograms (retina)

Physiological Measures

- Evoked Brain Potential (EP) from secondary task
  - Amplitude of EP to secondary task reflects the amount of resources dedicated to it
  - Measures residual capacity from primary task without directly measuring secondary task performance
- Pupil Diameter: highly correlated with resource demands of a variety of mental operations
- Heart-rate variability: decreases as mental workload increases (Mulder & Mulder, 1981); associated with decreased variability in respiration: *sinus arrhythmia*

Pupil Diameter

- No Task
- Blanks
- Misses
- Hits
- Math Problem

Amplitude of Transient Evoked Response (P300) Elicited by Infrequent Counted tones When Presented Alone or Concurrently with a Visual Detection Task of Varying Workload.
Subjective Measures

- Basic Concept: ask the operator to assess their own workload
  - Relies on introspection -- generally not a good idea
  - Workload a multi-dimensional construct that reflects
    - Mental effort
    - Stress
    - Frustration
    - Physical effort
    - Perception of performance
    - Temporal demands (or time load)

- Greater reliability can be achieved if
  - structured questionnaire is used to assess operator's perceptions along each of these dimensions
  - prescribed method is used to combine ratings on each dimension into a single workload scale
  - Examples of questionnaires
    - NASA-TLX scale (Hart & Staveland, 1988): Measures five 7-point scales
    - SWAT (Reid & Nygren, 1988): Measures three 3-point scales
    - Cooper-Harris: Manual control characteristics

Subjective Measures: SWAT

- Developed by the US Air Force.
- There are 3 Sources of workload: Time, Effort, and Stress.
- Each has 3 Levels 1=Low, 2=Medium, 3=High.
- Begin by putting the 27 Cards (3 Sources X 3 Levels X 3 Combinations) into order from 1-27.
- Subjects rate each EVENT by giving a number for each, (e.g., Time=2, Effort=1, Stress=3).
- Looking up this combination in the card sort gives the workload on a 0-100 Scale.

Subjective Measures: NASA-TLX

- Developed by ...
- There are SIX Sources of Workload: Temporal Demand, Effort, Stress, Own Performance, Frustration, Physical Demand
- Each is compared pairwise against the others to give a rank order (0-5).
- Subjects rate each EVENT by giving a 0-100 score for each Source.
- These values are multiplied by the RANK and the total is divided by 15 to get the Workload Score on a 0-100 Scale.
Primary Task measurement

► Advantages
  ▪ Workload reflected directly by performance outcome.
  ▪ Non-invasive and non-**obtrusive**.
  ▪ Tracks changes in workload dynamically. (i.e., as performance proceeds)
  ▪ Uncontaminated by memory issues

► Disadvantages
  ▪ Reserve capacity can make primary task performance insensitive to changes in task difficulty
  ▪ Primary task measures can be **unselective**, respond to factors other than changes in mental workload
  ▪ Problems with **diagnosticity**
  ▪ Problems with **reliability** and **bandwidth** of measures used during "real-world" performance

Secondary Task Measurement

► Advantages
  ▪ Allows comparison of different primary tasks whose performance cannot be directly compared due to differences in measures
  ▪ Measure of secondary task performance is the same for each--it is **selective**

► Disadvantages
  ▪ Difficult to take into account multiple resources
  ▪ Must insure that secondary task is drawing on the same resources as primary task or the measure will be **insensitive**
  ▪ Secondary tasks are sometimes **obtrusive**
  ▪ Solution: embedded secondary task

Physiological Measures

► Evoked Brain Potential (EP) from secondary task
  ▪ Advantages
    ▪ **Diagnostic**: measures perceptual/cognitive processing load but not response load
    ▪ Can be less **obtrusive**: no overt response required
  ▪ Disadvantages
    ▪ Technically difficult to employ, particularly in the field

► Heart-rate variability
  ▪ Advantages
    ▪ Relatively **sensitive** measure
    ▪ Can be **unobtrusive**
    ▪ High reliability and bandwidth
  ▪ Disadvantages
    ▪ **undiagnostic**: reflects demand of all resources

Physiological Measures

► Pupil Diameter
  ▪ Advantages
    ▪ Highly **sensitive** measure
    ▪ **Unobtrusive** if measurement device is subtle
    ▪ High bandwidth -- changes occur quickly
  ▪ Disadvantages
    ▪ **Undiagnostic**
    ▪ **Unreliable**: changes are small, difficult to measure
    ▪ **Unselective**: affected by ambient light or emotional arousal

Physiological Measures

► Subjective Measures
  ▪ Advantages
    ▪ Fairly low **obstrusiveness**
    ▪ Good **diagnosticity** with multiple sub-scales
    ▪ Fast to conduct
  ▪ Disadvantages
    ▪ Low reliability - relying on the operator to introspect
    ▪ Low bandwidth - fast changes in workload are difficult to assess
    ▪ Insensitive to data-limited tasks
    ▪ Unselective: response varies more with number of tasks than individual task complexity

Stress

► Arousal: level of physiological and psychological activity at any given moment; occurs on a continuum
► Stress: physiological and psychological response to a challenge that requires some form of adjustment
► Anxiety: negative end of arousal; characterized by worry, nervousness, and apprehension
► Trait Anxiety: one's predisposition to perceive challenges; acquired behavioral tendency
► State Anxiety: moment-to-moment anxiety
  ▪ Cognitive State Anxiety: the negative thoughts and worries one has in an anxious moment
  ▪ Somatic State Anxiety: how the physiology responds in anxious moments – real or perceived
Stress
► Stress is a reaction to stressors
► Stressors: circumstances that disrupt, threaten to disrupt, or are perceived to disrupt or threaten one’s well-being and tax one’s ability to cope
  ▪ Produce physiological changes (e.g., increased heart rate)
  ▪ Affect information processing, sometimes positively, sometimes negatively
► Lazarus’s Cognitive Theory of Stress
  ▪ It is one’s perception of a stressor that causes stress – not the stressor itself
► What causes stress?
  ▪ A perceived imbalance between the challenge (physical or psychological) placed on an individual and their ability to overcome the challenge.

Stress Responses
► Physical Stress Responses:
  ▪ activation of sympathetic branch of the autonomic nervous system
  ▪ short-term (acute): flight or fight syndrome
    ▪ rapid breathing, increased heart rate, sweating, general shakiness -- usually later
  ▪ long-term (chronic): general adaptation syndrome
    ▪ Alarm reaction: fight or flight
    ▪ Resistance: slow drain of bodily resources from increase in blood sugar, blood pressure, and muscle tension
    ▪ Exhaustion: body’s reserves are used up

Stress Responses
► Behavioral Stress Responses
  ▪ strained facial expressions, perspiration, shaky voice, tremors or muscle spasms, jumpiness
  ▪ decreased physical coordination
  ▪ aggression
  ▪ giving up -- learned helplessness
  ▪ self-indulgence
► Emotional Stress Responses
  ▪ negative shift (guilt or sadness)
  ▪ frustration, fear, anxiety
  ▪ chronic stress can lead to burnout and/or post traumatic stress disorder (battle fatigue)

Stress and Human Information Proc.
► Arousal and the Yerkes-Dodson Law (1908)
  ▪ inverted “U”-shaped function
► Easterbrook (1959)
  ▪ at low stress: “energizing” effect that increases arousal (resources available)
  ▪ at high stress: high arousal degrades selective attention – narrowing
  ▪ stress & task complexity/training
► Attentional Narrowing
  ▪ Degradation of peripheral processing: Weltman, Smith, and Egstrom (1971)
  ▪ Facilitation in Stroop task: Houston (1969)

Stress and Human Information Proc.
► Working Memory
  ▪ Stress decreases working memory capacity -- distraction
    ▪ critical for learning, difficult to learn under high stress
► Long-term memory
  ▪ hinders encoding (attentional effect)
  ▪ does not hinder retrieval of highly learned material (automatic processes)
► Strategic Shifts
  ▪ emphasis on speed over accuracy
  ▪ signal detection: observer becomes riskier
  ▪ operator may feel the need “to do something”
► Decision making: “Cognitive tunneling” or “perseveration” (due to reduction in attentional and memory capacities?)

Mediating effects of stress
► Predictability
► Locus of control (personality)
  ▪ internal vs. external
► Optimism and cognitive interpretation of stressors
► Training: develop automaticity so the effects of stress are inconsequential
Coping with stress

- Design solutions
  - Displays and perceptual narrowing: reduce clutter
  - Norman’s Design Principles
    - Visibility, mappings, feedback
    - reduce working memory load
    - support automatic processing
  - Procedural instructions: positive (tell the person what to do) better than negative (what not to do)

- Operator Solutions
  - Training
  - Relaxation techniques

Effects/Symptoms of Fatigue

- Degraded cognitive functions (judgment, decision making)
- Decreased alertness (situational awareness, perception, vigilance)
- Errors (missed cues, sloppiness, misunderstanding of communication)
- Impaired concentration, orientation and memory (tend to forget things)
- Mood (complacency, irritability)
- Slowed reaction times
- Degraded skills
- Weakened immune system
- Lethargy/sleepiness

Fatigue

- Causes
  - High intensity workloads (critical decision-making overload or work stress) → cognitive or physical
  - Continuous workloads without breaks
  - Physical environment: temperature, humidity, altitude, air quality, noise and vibration
  - Night or late afternoon shifts increase fatigue because of Circadian rhythm lows (2-5 AM) and the afternoon dip (3-5 PM) → A number of biological variables exhibit a 24-hour periodicity or rhythm (wakefulness, hormones, respiratory and heart rates, blood pressure).
  - Low activity, repetitive tasks, and monitoring roles (in general boring tasks)
  - Disabling condition: Chronic Fatigue Syndrome

Coping with Fatigue

- Alertness strategies
  - Preventive strategies used before or between tasks to reduce the effects of fatigue
  - Rest before long shift, short naps in between
  - Practice, adaptation (for humidity & heat)
- Operational strategies
  - Used during tasks to maintain performance.
  - Do not address the underlying physiological mechanisms, but manage the effects of fatigue
  - Caffeine, snacking, stretching, walking around
  - Adrenalin? Sugar?

- Current policy on work/rest ratio:
  - 1 hr rest for every 2 hrs work; ideally no more than 14 hr shift
  - Over 16 hrs—must justify and document shift length, and implement countermeasures

Why 14-hr?

Preventing Fatigue: Allowances

- Provide minimum of 9 – 10 % constant allowance for:
  - personal needs (to maintain general wellbeing): restroom breaks, drinking
  - basic fatigue (rest needed to recover from energy expended, relieve monotony, stress, etc.)
- Add allowances to normal time as a percentage of the normal time to complete the task.
- How to determine ‘normal time’?
  - Production studies: observation of all activity in an extended interval (record duration and reason for all idle time).
  - Work sampling studies: take a large number of random samples of the work. Walk in to work area at random times, record total number of delays, and productive work.