

- 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



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

Physiological Measures

- heart rate (ECG)
- blood pressure
- respiratory rate variability
- tidal volume
- ventilation galvanic skin response
- evoked response amplitude
- evoked response latency
- electroencehpalogram (EEG)
- spectral components
- time domain, ►
- flicker fusion frequency
- pupil diameter
- electromyograms (muscles)
- electrooculograms (retina)

- 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













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)



Subjective Measures

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-pont 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.



Three-Point Rating Scales for the Time, Mental Effort, and Stress Load Dimensions of the Subjective Workload Assessment Technique (SWAT)

TIME LOAD	MENTAL EFFORT LOAD	STRESS LOAD
 Often have spare time. Interruptions or overlap among activities occur infrequently or not at all. 	 Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention. 	 Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.
 Occasionally have spare time. Interruptions or overlap among activities occur frequently. 	 Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required. 	 Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.
3. Almost never have spare time. Interruptions or overlap among activities are very frequent or occur all the time.	 Extensive mental effort and concentration are necessary. Very complex activity requiring total attention. 	 High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

TITLE	END POINTS	DESCRIPTION
Mental demand	Low/High	How much mental and perceptual activity was require (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving
Physical demand	Low/High	How much physical activity was required (e.g., pushin pulling, turning, controlling, activating, etc.)? Was th task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal demand	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantit
Performance	Low/High	How successful do you think you were in accomplishin the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physical to accomplish your level of performance?
Frustration level	Low/High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, complacent did you feel during the task?

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

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



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



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

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



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

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.

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?)



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 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)



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

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.

