

Diagnosticity and Multidimensional Subjective Workload Ratings

Tsang & Velazquez (1996)

Workload Profile Rating Scale

(Range: 0.0 – 1.0; Proportion of Available Resource Utilized)

Workload Dimensions								
	Stage of processing		Code of processing		Input		Output	
Task	Perceptual/ Central	Response	Spatial	Verbal	Visual	Auditory	Manual	Speech

Obviously inspired by Wickens' Multiple Resource Theory

Appendix A. Workload dimensions in the Workload Profile.

1. *Stages of processing*

- (1) *Perceptual/central processing*. These are attentional resources required for activities like perceiving (detecting, recognizing, and identifying objects), remembering, problem-solving, and decision making.
- (2) *Response processing*. These are attentional resources required for response selection and execution. For example, there are three foot pedals in a standard shift automobile; to stop the automobile, we have to select the appropriate pedal and step on it.

2. *Processing codes*

- (1) *Spatial processing*. Some tasks are spatial in nature. Driving, for example, requires paying attention to the position of the car, the distance between the current position of the car and the next stop sign, the geographical direction that the car is heading, etc.
- (2) *Verbal processing*. Other tasks are verbal in nature. For example, reading involves primarily processing of verbal, linguistic materials.

3. *Input modality*

- (1) *Visual processing*. Some tasks are performed based on the visual information received. For example, playing basketball requires visual monitoring of the physical location and velocity of the ball. Watching TV is another example of a task that requires visual resources.
- (2) *Auditory processing*. Other tasks are performed based on auditory information. For example, listening to the person on the other end of the telephone is a task that requires auditory attention. Listening to music is another example.

Note that spatial information may be processed visually or auditorily. For example, you can get to a new restaurant by following a map (visual processing) or by following the directions spoken by your friend (auditory processing). Similarly, verbal information may be processed visually or auditorily. Listening to the news on the radio requires auditory processing of verbal materials; reading the news from the newspaper requires visual processing of verbal materials.

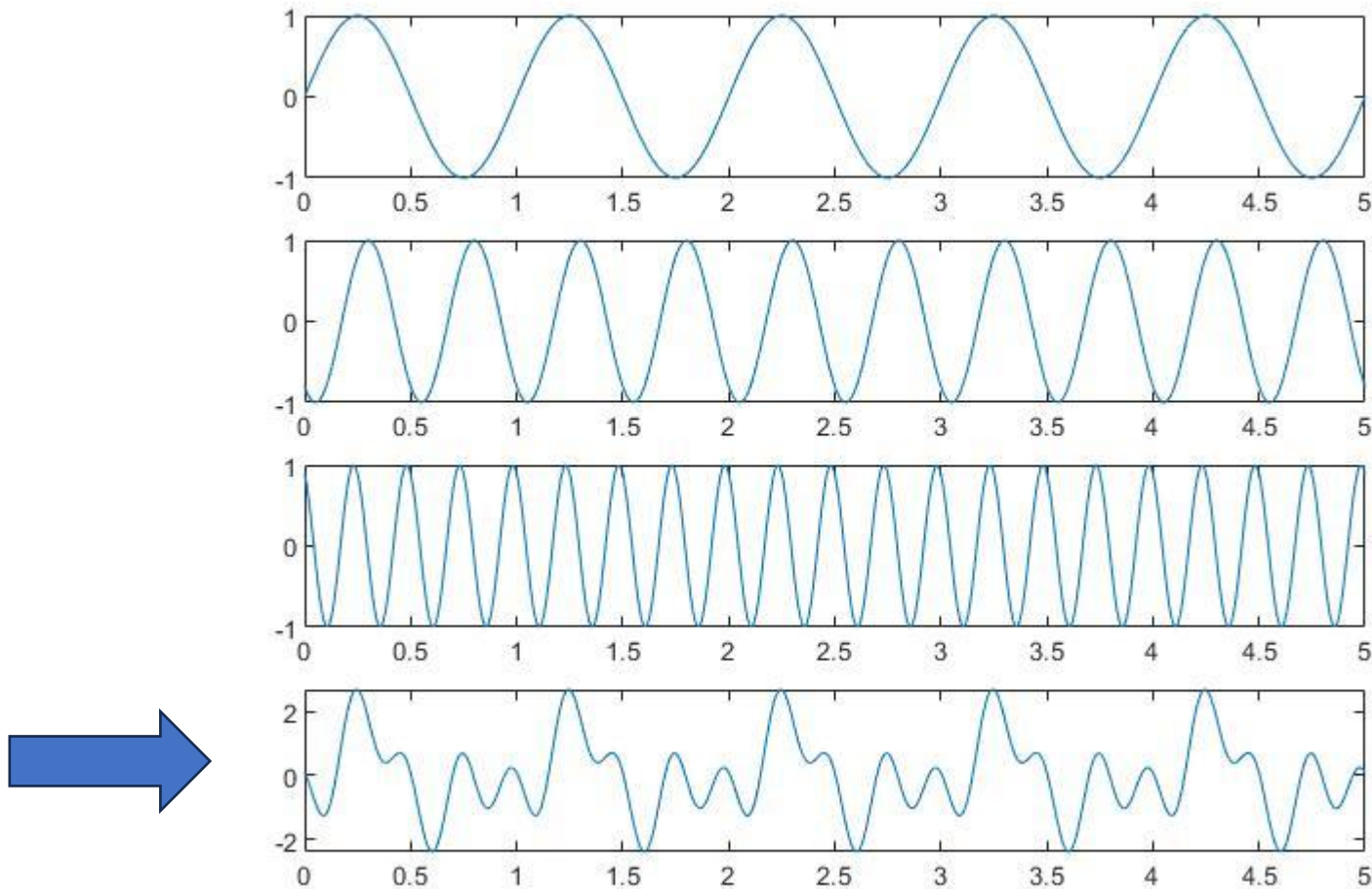
4. *Output modalities*

- (1) *Manual responses*. Some tasks require considerable attention for producing the manual response as in typing or playing a piano.
- (2) *Speech responses*. Other tasks require speech responses instead. For example, engaging in a conversation requires attention for producing the speech responses.

Experimental Details

- Two laboratory tasks:
 - Sternberg Memory Task
 - Continuous 1-D Tracking Task
- Sternberg Task
 - Search contents of working memory; $DV = RT$
 - Two levels of difficulty
 - SB2: memory set size = 2 letters
 - SB4: memory set size = 4 letters
- Tracking Task
 - Compensatory tracking; keep moving cursor on central target
 - Sum-of-sines “forcing function”; $DV = RMSE$
 - Two levels of difficulty
 - TR1: forcing function = speed (1st-order)
 - TR2: forcing function = acceleration (2nd-order)

Sample “Forcing Function” for Tracking Task (Sum of Sines)



Experimental Details

- Participants experience the following conditions:
Single Task: SB2, SB4, TR1, TR2
Dual-Task: SB2TR1, SB4TR1, SB4TR1, SB4TR2
- Conditions are presented in randomized order
- Subjective workload ratings obtained for each condition
Bedford scale
Magnitude estimation (Relative to SB2 = 100 modulus)
Workload Profile
PC – Perceptual/Central Processing; RP – Response Selection
SP – Spatial Processing; VB – Verbal Processing
VS – Visual Processes; MN – Manual Processes
{Auditory input and Speech output excluded}

Diagnosticity Results

Canonical Discriminant Analysis

- Canonical discriminant analysis is the equivalent of a canonical correlation analysis between a set of quantitative variables (e.g., the six Workload Profile ratings) and a set of orthogonal dummy variables coded to represent the classification variables (e.g., the four dual-task conditions)
- Dummy (Classification) Variables:

SB2TR1	0	0	0
SB2TR2	0	0	1
SB4TR1	0	1	0
SB4TR2	1	0	0
- Quantitative Variables Set:
[PC RP SP VB VS MN]

Canonical Discriminant – Single Task Condition

Table 3. Canonical correlations between task conditions and workload profiles.

		Structure coefficients	
		Canonical Variate 1	Canonical Variate 2
Single-task workload dimensions			
	PC	−0.36	0.81
	RP	0.16	0.54
	SP	0.93	0.25
	VB	−0.88	0.27
	VS	0.15	0.17
	MN	0.23	0.34
Redundancy		.26	.03
Task means			
	TR1	1.92	−0.48
	TR2	2.37	0.48
	SB2	−1.89	−0.36
	SB4	−2.40	0.37
R_c^2		0.83	0.16

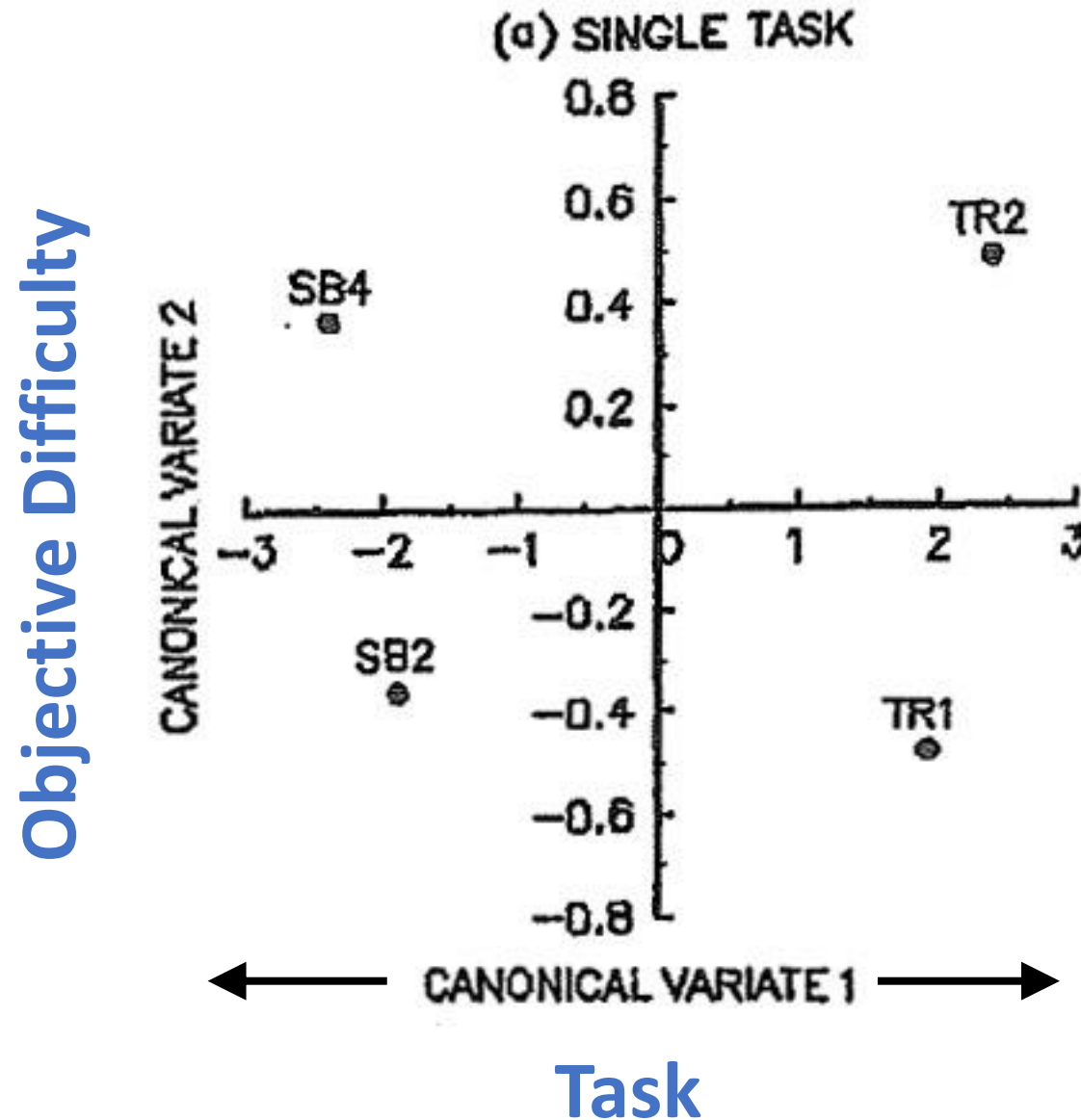
First and second Canonical Variates are significant

First Canonical variate accounts for 26% of the variation in the Workload Profiles across conditions

Wilkes Lambda ($p < 0.0001$) Significant Workload Profile differences across conditions

Highly meaningful dimension

Significant Separation of Profiles by Conditions



Single-Task Workload Profiles annotated with high-value “structural coefficients” from the Canonical Discriminant Analysis

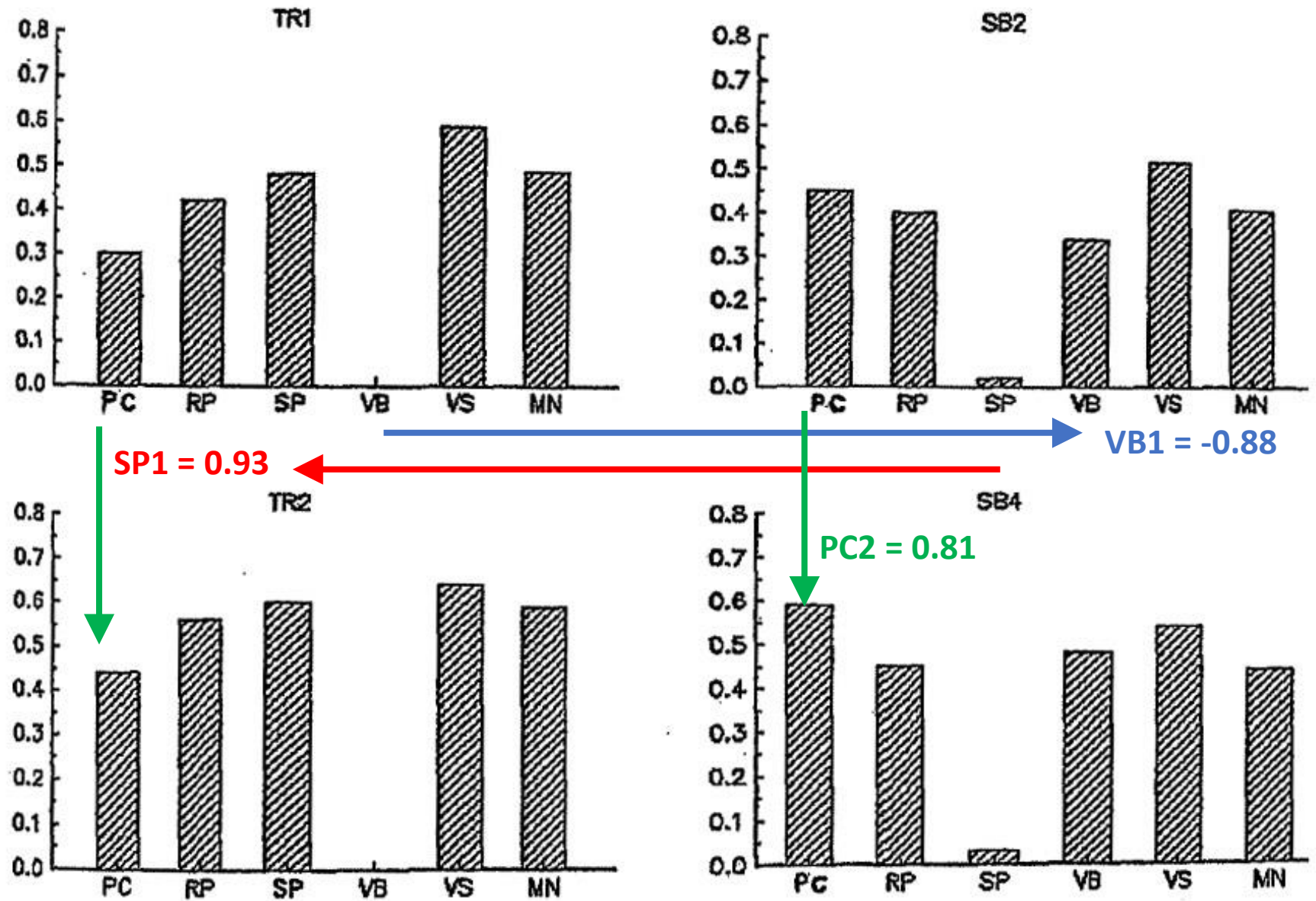


Figure 3. Single task mean subjective ratings on the six workload dimensions in the Workload Profile procedure. PC = perceptual/central, RP = response, SP = spatial, VB = Verbal, VS = visual, MN = manual.

Canonical Discriminant – Dual Task Conditions

Table 3. Canonical correlations between task conditions and workload profiles.

		Structure coefficients	
		Canonical Variate 1	Canonical Variate 2
Dual-task workload dimension	PC	0.64	0.68
	RP	0.70	0.45
	SP	0.84	0.09
	VB	0.25	0.82
	VS	0.49	0.38
	MN	0.63	0.21
		0.08	0.03
Redundancy			
Task means	TR1SB2	-0.56	-0.32
	TR1SB4	-0.44	0.41
	TR2SB2	0.43	-0.38
	TR2SB4	0.57	0.29
R_c^2		0.21	0.13

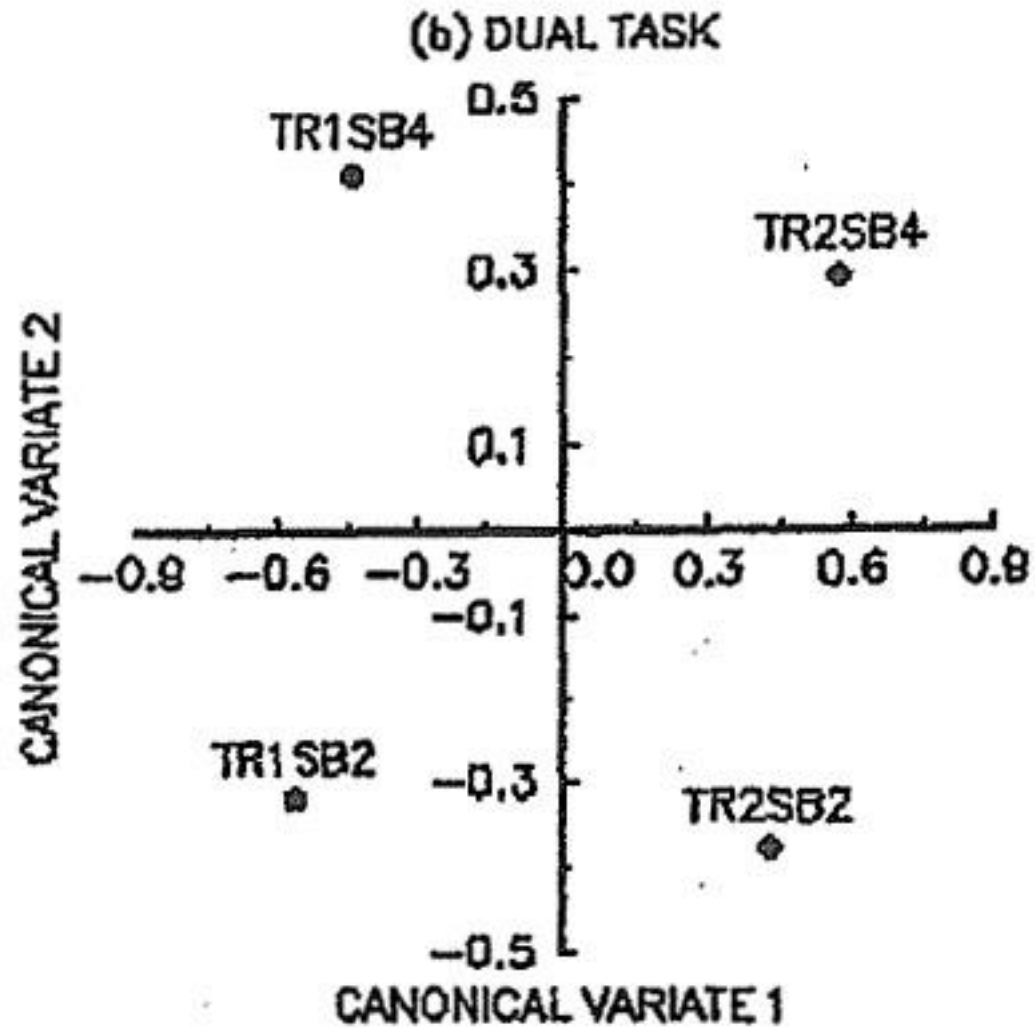
Only the First Canonical Variate was successful at discriminating among conditions

First Canonical variate accounts for 8% of the variation in the Workload Profiles across conditions

Wilkes Lambda ($p < 0.001$) Significant Workload Profile differences across conditions

Moderately meaningful dimension

Memory Task Load



Tracking Task Load

Dual-Task Workload
Profiles annotated with
high-value “structural
coefficients” from the
Canonical Discriminant
Analysis

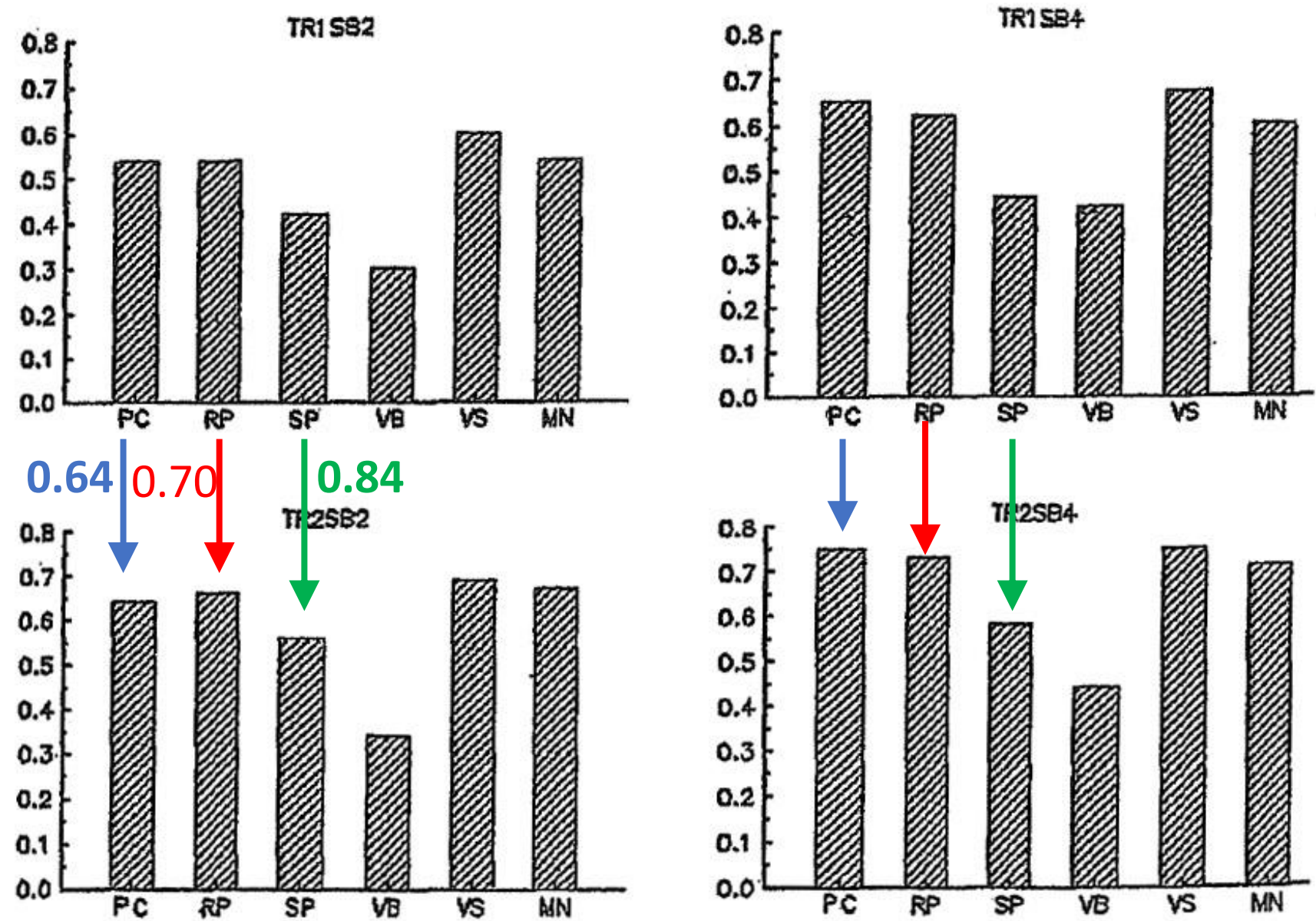


Figure 4. Dual task mean subjective ratings on the six workload dimensions in the Workload Profile procedure. PC = perceptual/central, RP = response, SP = spatial, VB = verbal, VS = visual, MN = manual.

Sensitivity Analysis

- **(5) ANOVAs**

[2] Blocks (Early; Late) x [6-8] Task Conditions

Dependent variables:

RMSE, RT, Bedford, Psychophysical, Sum of WP Ratings

- **(2) MANOVAs**

[4] Dual-Task Conditions

Dependent variable sets:

[RMSE, RT] i.e., Performance

[PC,RP,SP,VB,VS,MV] i.e., six Workload Profile scores

ANOVA Results

- Significant BLOCK (Practice) effect for all ANOVAs:
improved performance; decreased subjective workload
- Significant TASK main effect for all ANOVAs:
denoting sensitivity to the task load manipulations

POST HOCs:

- Significant differences across Tracking task load conditions:
error increased for all second-order tracking task conditions
- RT fastest for SB2, slowest for TR2SB4 condition
- Dual-task RT always slower than single-task RT
- As predicted by Multiple Resource Theory, TR2SB4 demonstrated the highest tracking error and slowest RT

Table 5. Comparison of the workload assessment instruments.

	Performance		Subjective		
	RMSE	RT	Bedford	Psychophysical	Workload profile

Subjective approaches

Dimensionality	Unidimensional		Unidimensional	Multidimensional
Absolute versus relative	Absolute		Relative	Absolute
Immediate versus retrospective	Immediate		Retrospective	Retrospective
Time to complete	Several seconds		Few minutes	15–30 minutes

Sensitivity

Univariate effect size	75	.30	.37	.57	.28
Multivariate effect size		.97			.73

Sum WP

[RMSE, RT]

[PC,RP,SP,VB,VS,MN]

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Evaluation of Subjective Mental Workload: A Comparison of SWAT, NASA-TLX, and Workload Profile Methods

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TABLE 3
Workload Means and Standard Deviations for Each Instrument

		<i>Mean</i>	<i>SD</i>
M2	TLX	7.44	6.58
	SWAT	4.07	1.84
	WP	1.24	0.79
M4	TLX	8.81	7.55
	SWAT	4.09	1.33
	WP	1.60	0.91
S3	TLX	16.53	11.01
	SWAT	5.70	2.37
	WP	1.72	0.81
S1	TLX	25.97	10.95
	SWAT	7.32	1.83
	WP	2.61	0.93
M2S3	TLX	32.42	18.30
	SWAT	9.73	2.39
	WP	2.96	0.97
M4S3	TLX	33.17	17.06
	SWAT	10.94	3.15
	WP	3.30	0.82
M2S1	TLX	39.30	16.40
	SWAT	13.53	3.01
	WP	3.44	0.82
M4S1	TLX	46.28	17.61
	SWAT	14.51	4.13
	WP	4.32	1.02

Single Task ANOVAs: (2) Task Load Levels; Dual-Task ANOVAs: (2) Memory Task Levels x (2) Tracking Task Levels
Dependent Variable: Global Workload Score WP = Sum of WP scores (0.0-6.0)

Sensitivity Analysis

TABLE 4 Summary of ANOVAs for Each Instrument				
Task	Variable	Instrument	F(1,11)	p
Single	Memory set size	TLX	1.09	0.319
		SWAT	0.00	0.976
		WP	28.72	0.000**
	Path width	TLX	48.86	0.000**
		SWAT	14.20	0.003**
		WP	50.43	0.000**
Dual	Memory set size	TLX	13.81	0.003**
		SWAT	4.52	0.057
		WP	70.39	0.000**
	Path width	TLX	43.67	0.000**
		SWAT	18.14	0.001**
		WP	30.93	0.000**
	Interaction	TLX	4.86	0.500
		SWAT	0.03	0.864
		WP	6.22	0.030*

* $p < .05$; ** $p < .01$.

Appendix:

Predicting Task Performance: Regression Models

Table 1. Multiple regression analysis models and squared multiple correlations.

							R^2			
							Full model		Reduce model	
Multiple Regression model							With	Without	With	Without
Single ← RT	PC RP SP VB VS MN	Memory Size				Block	.84****	.51****	.71****	.26****
	Single-task ratings									
Single ← RMSE	PC RP SP VB VS MN		Track order			Block	.93****	.86****	.43****	.18****
	Single-task ratings									
Dual ← ZSUM	PC RP SP VB VS MN	Memory Size	Track order	M×T		Block	.81****	.79****	.56****	.15**
	Dual-task ratings									
Dual ← ZSUM	PC RP SP VB VS MN	Memory Size	Track order	M×T		Block	.82****	.79****	.30***	.10*
	Single memory + Single tracking ratings									

Notes. PC = perceptual/central, RP = response, SP = spatial, VB = verbal, VS = visual, MN = manual; full model included all independent variables listed, reduced model included only the subjective ratings for the six workload dimensions; with = with subject as a classification variable in the model, without = without the subject variable; M×T = Memory set size × tracking order interaction; ZSUM = sum of the standardized dual task RT and RMSE; **** $p < .0001$ that R^2 is significantly different from zero, *** $p < .001$, ** $p < .01$, * $p < .05$.