Measuring the effectiveness of a cognitive aid in Deep Space Network Operations

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CANBERRA
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Background

Follow the Sun Operations (FtSO)

- Increase in missions, higher data rates, and more complex procedures

  (Choi, Verma, & Malhotra, 2016)

- Automation improvements designed to manage LCO workload and efficiency are in development (DSN Functions, n.d.)

Background

DSN Complex Event Processing (DCEP)

- Method of combining streams data from different sources in order to identify meaningful events and patterns (Choi et al., 2016)
- Ongoing situations are matched to incidents previously captured as discrepancy reports
- DCEP output guides decision-making

Background

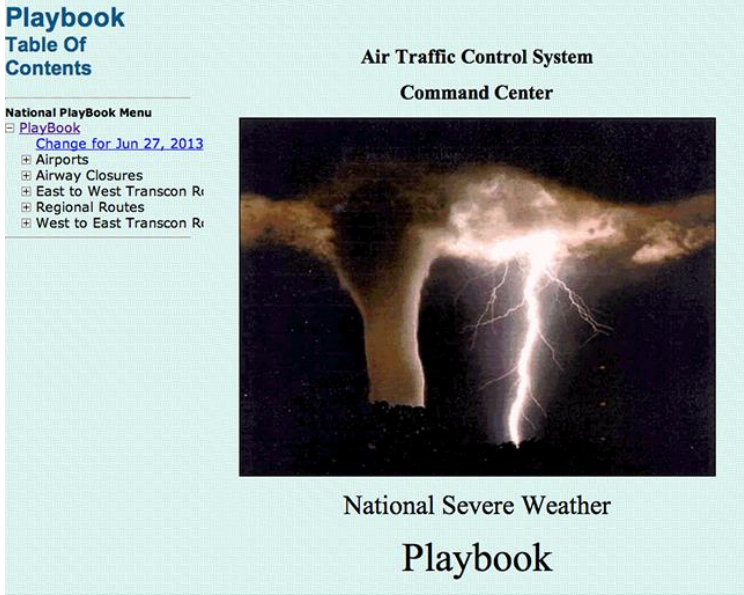
Cognitive Aids

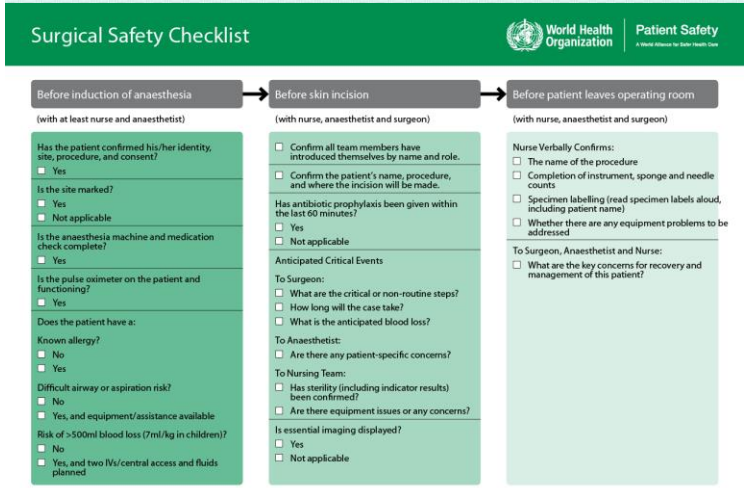
- A cognitive aid is a presentation of prompts aimed to encourage recall of information in order to increase the likelihood of desired behaviors, decisions, and outcomes
  (Fletcher & Bedwell, 2014)

Background

Cognitive Aids

- Include, but are not limited to:
  - Checklists, flowcharts, posters, sensory cues, safety systems, alerts, and decision support tools (Levine, DeMaria, Schwartz, & Sim, 2013; Singh, 1998)





Background

Cognitive Aids

- Improve performance
  - Greater adherence to recommended procedures for the most common intraoperative emergencies (Arriaga et al., 2013)
  - Higher average expected arrival time adherence (Van de Merwe, Oprins, Eriksson, & Van der Plaat, 2012)
- Reduce workload
  - Lower subjective workload ratings and less device inputs (Van de Merwe, Oprins, Eriksson, & Van der Plaat, 2012)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Background

Expertise

- Cognitive load theory (Sweller, 1988)
  - Experts use *schemas* to efficiently process interrelated elements in complex tasks (Redding & Cannon, 1992)
  - Experts are able to solve domain-specific problems more efficiently when compared to novices

Background

Expertise

- Facilitates performance
  - Experts excelled in reconstructing real chess positions (Simon & Chase, 1973)
  - Journeymen had less losses of separation without automated tools (Kiken, 2012)

Background

Expertise

- Mitigates workload
  - Journeymen significantly faster at answering probe ready prompts (Kiken, 2012)
  - Expert surgeons completed more secure sutures than novices (Zheng, 2009)

Background

Acceptance

- Technology Acceptance Model (Davis,1989)
  - Perceived Usefulness
    - as the degree to which a person believes that using a particular system will enhance his or her job performance
  - Perceived Ease of Use
    - as the degree to which a person believes that using a system will be free of effort.

Method

Purpose

- Examine how a cognitive aid affects the performance and workload of expert and novice LCOs in a DSN task
- Measure LCO acceptance of a cognitive aid

Method

Research Questions

1. What effect will the cognitive aid have on operator performance in the DSN framework?
2. What effect will the cognitive aid have on operator subjective workload in the DSN framework?
3. Will expert operators perform differently than novice operators with and without the cognitive aid?
4. Will novice operators have higher acceptance ratings for the cognitive aid compared to experts?

Method

Task

- Diagnose and resolve any issues that occur within the track
- 4 scenarios created with help of a subject matter expert
- Example scenario: Light Rain
- Context:
  - “You are tracking Voyager 2 on DSS 43 located in Canberra. The track is cruising. No planned LOS are on the schedule.”

Method

Experimental Design

- 2 Group X 2 Assistance mixed ANOVAS
- Independent variables
  - Group
    - Expert/Novice
  - Assistance
    - Cognitive aid/No cognitive aid
- Dependent variables
  - Interactions
    - Clicks
  - Performance
    - Time on task
  - Subjective workload
    - NASA TLX
  - Technology acceptance
    - TAM PU scale
  - Think aloud

Results

Interactions (clicks)

Within-Subjects Factors

Measure: MEASURE_1

assistance	Dependent Variable
1	cogaid_clicks
2	nocogaid_clicks

Between-Subjects Factors

		Value Label	N
group	0	expert	4
	1	novice	4

Descriptive Statistics

	group	Mean	Std. Deviation	N
cogaid_clicks	expert	3.88	1.797	4
	novice	1.54	1.417	4
	Total	2.71	1.949	8
nocogaid_clicks	expert	4.00	1.780	4
	novice	2.75	2.398	4
	Total	3.38	2.066	8

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
assistance	Sphericity Assumed	1.778	1	1.778	.373	.564	.373	.081
	Greenhouse-Geisser	1.778	1.000	1.778	.373	.564	.373	.081
	Huynh-Feldt	1.778	1.000	1.778	.373	.564	.373	.081
	Lower-bound	1.778	1.000	1.778	.373	.564	.373	.081
assistance * group	Sphericity Assumed	1.174	1	1.174	.246	.637	.246	.071
	Greenhouse-Geisser	1.174	1.000	1.174	.246	.637	.246	.071
	Huynh-Feldt	1.174	1.000	1.174	.246	.637	.246	.071
	Lower-bound	1.174	1.000	1.174	.246	.637	.246	.071
Error(assistance)	Sphericity Assumed	28.604	6	4.767				
	Greenhouse-Geisser	28.604	6.000	4.767				
	Huynh-Feldt	28.604	6.000	4.767				
	Lower-bound	28.604	6.000	4.767				

a. Computed using alpha = .05

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	assistance	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
assistance	Linear	1.778	1	1.778	.373	.564	.373	.081
assistance * group	Linear	1.174	1	1.174	.246	.637	.246	.071
Error(assistance)	Linear	28.604	6	4.767				

a. Computed using alpha = .05

Results

Interactions (clicks)

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
cogaid_clicks	.044	1	6	.841
nocogaid_clicks	1.500	1	6	.267

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + group
Within Subjects Design: assistance

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Intercept	148.028	1	148.028	64.108	.000	64.108	1.000
group	12.840	1	12.840	5.561	.056	5.561	.507
Error	13.854	6	2.309				

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
3.042	.380	2.112	3.971

2. group

Measure: MEASURE_1

group	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
expert	3.938	.537	2.623	5.252
novice	2.146	.537	.831	3.460

3. assistance

Measure: MEASURE_1

assistance	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	2.708	.572	1.309	4.108
2	3.375	.747	1.548	5.202

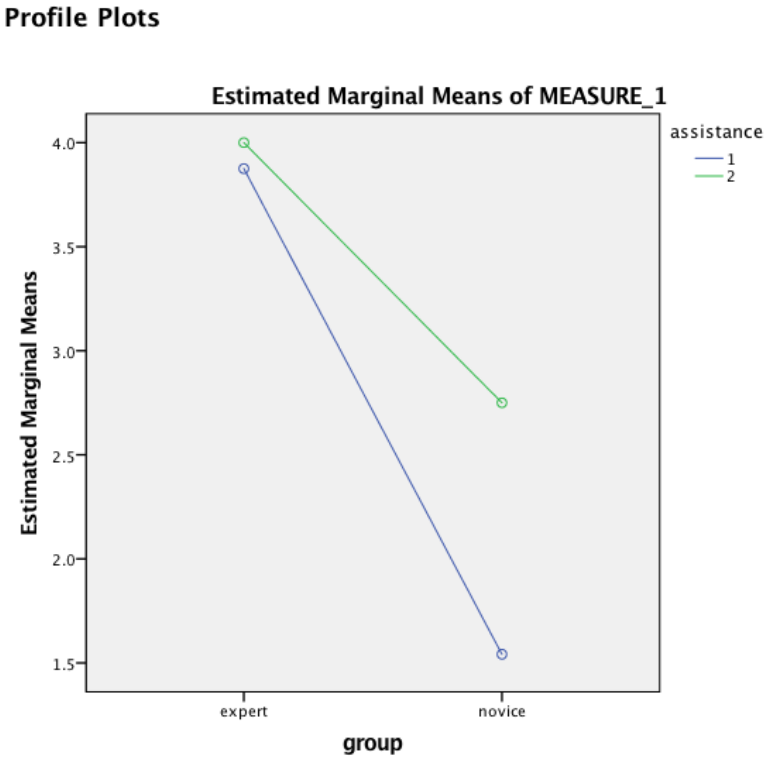
4. group * assistance

Measure: MEASURE_1

group	assistance	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
expert	1	3.875	.809	1.895	5.855
	2	4.000	1.056	1.417	6.583
novice	1	1.542	.809	-.438	3.521
	2	2.750	1.056	.167	5.333

Results

Interactions (clicks)



Results

Efficiency (time including timeouts)

General Linear Model

Within-Subjects Factors

Measure: MEASURE_1

assistance	Dependent Variable
1	cogaid_time_s
2	nocogaid_time_s

Between-Subjects Factors

		Value Label	N
group	0	expert	4
	1	novice	4

Descriptive Statistics

	group	Mean	Std. Deviation	N
cogaid_time_s	expert	253.1250	86.23164	4
	novice	309.0000	99.38729	4
	Total	281.0625	91.17113	8
nocogaid_time_s	expert	427.7500	82.65339	4
	novice	473.3750	115.01259	4
	Total	450.5625	95.87322	8

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
assistance	Sphericity Assumed	114921.000	1	114921.000	26.970	.002	26.970	.989
	Greenhouse-Geisser	114921.000	1.000	114921.000	26.970	.002	26.970	.989
	Huynh-Feldt	114921.000	1.000	114921.000	26.970	.002	26.970	.989
	Lower-bound	114921.000	1.000	114921.000	26.970	.002	26.970	.989
assistance * group	Sphericity Assumed	105.063	1	105.063	.025	.880	.025	.052
	Greenhouse-Geisser	105.063	1.000	105.063	.025	.880	.025	.052
	Huynh-Feldt	105.063	1.000	105.063	.025	.880	.025	.052
	Lower-bound	105.063	1.000	105.063	.025	.880	.025	.052
Error(assistance)	Sphericity Assumed	25566.688	6	4261.115				
	Greenhouse-Geisser	25566.688	6.000	4261.115				
	Huynh-Feldt	25566.688	6.000	4261.115				
	Lower-bound	25566.688	6.000	4261.115				

a. Computed using alpha = .05

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	assistance	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
assistance	Linear	114921.000	1	114921.000	26.970	.002	26.970	.989
assistance * group	Linear	105.063	1	105.063	.025	.880	.025	.052
Error(assistance)	Linear	25566.688	6	4261.115				

a. Computed using alpha = .05

Results

Efficiency (time including timeouts)

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
cogaid_time_s	.127	1	6	.734
nocogaid_time_s	2.048	1	6	.202

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + group
Within Subjects Design: assistance

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Intercept	2141100.56	1	2141100.56	148.425	.000	148.425	1.000
group	10302.250	1	10302.250	.714	.430	.714	.111
Error	86552.938	6	14425.490				

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
365.813	30.027	292.340	439.285

2. group

Measure: MEASURE_1

group	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
expert	340.438	42.464	236.532	444.343
novice	391.188	42.464	287.282	495.093

3. assistance

Measure: MEASURE_1

assistance	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	281.063	32.895	200.570	361.555
2	450.563	35.408	363.923	537.202

4. group * assistance

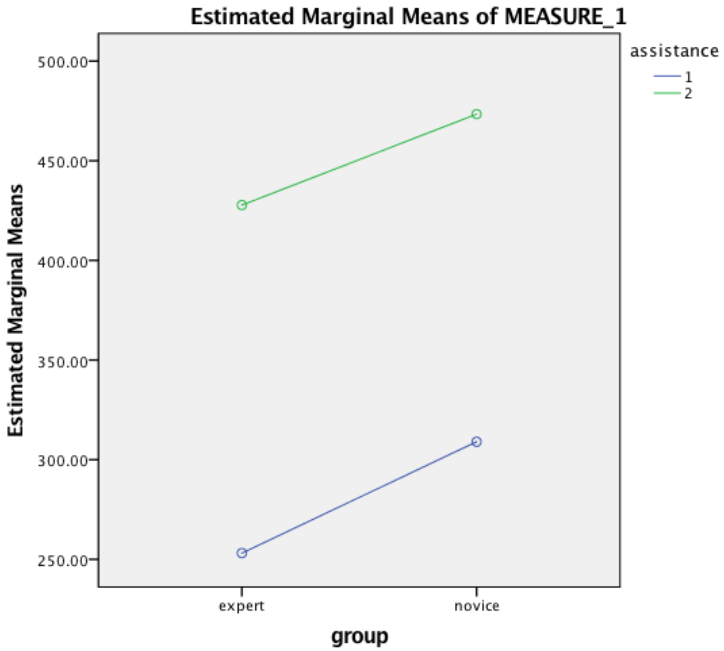
Measure: MEASURE_1

group	assistance	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
expert	1	253.125	46.521	139.292	366.958
	2	427.750	50.074	305.223	550.277
novice	1	309.000	46.521	195.167	422.833
	2	473.375	50.074	350.848	595.902

Results

Efficiency (time including timeouts)

Profile Plots



Results

Efficiency (time including timeouts)

Within-Subjects Factors

Measure: MEASURE_1

assistance	Dependent Variable
1	cogaid_time_to
2	nocogaid_time_to

Between-Subjects Factors

		Value Label	N
group	0	expert	4
	1	novice	3

Descriptive Statistics

	group	Mean	Std. Deviation	N
cogaid_time_to	expert	253.1250	86.23164	4
	novice	263.8333	50.76006	3
	Total	257.7143	67.89382	7
nocogaid_time_to	expert	323.3750	99.12566	4
	novice	340.3333	156.09079	3
	Total	330.6429	114.52755	7

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
assistance	Sphericity Assumed	18459.054	1	18459.054	3.125	.137	3.125	.301
	Greenhouse-Geisser	18459.054	1.000	18459.054	3.125	.137	3.125	.301
	Huynh-Feldt	18459.054	1.000	18459.054	3.125	.137	3.125	.301
	Lower-bound	18459.054	1.000	18459.054	3.125	.137	3.125	.301
assistance * group	Sphericity Assumed	33.482	1	33.482	.006	.943	.006	.050
	Greenhouse-Geisser	33.482	1.000	33.482	.006	.943	.006	.050
	Huynh-Feldt	33.482	1.000	33.482	.006	.943	.006	.050
	Lower-bound	33.482	1.000	33.482	.006	.943	.006	.050
Error(assistance)	Sphericity Assumed	29538.875	5	5907.775				
	Greenhouse-Geisser	29538.875	5.000	5907.775				
	Huynh-Feldt	29538.875	5.000	5907.775				
	Lower-bound	29538.875	5.000	5907.775				

a. Computed using alpha = .05

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	assistance	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
assistance	Linear	18459.054	1	18459.054	3.125	.137	3.125	.301
assistance * group	Linear	33.482	1	33.482	.006	.943	.006	.050
Error(assistance)	Linear	29538.875	5	5907.775				

a. Computed using alpha = .05

Results

Efficiency (time including timeouts)

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
cogaid_time_to	.593	1	5	.476
nocogaid_time_to	.690	1	5	.444

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + group
Within Subjects Design: assistance

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Intercept	1194834.67	1	1194834.67	78.475	.000	78.475	1.000
group	656.095	1	656.095	.043	.844	.043	.053
Error	76128.333	5	15225.667				

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
295.167	33.320	209.516	380.818

2. group

Measure: MEASURE_1

group	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
expert	288.250	43.626	176.106	400.394
novice	302.083	50.375	172.591	431.576

3. assistance

Measure: MEASURE_1

assistance	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	258.479	28.301	185.729	331.229
2	331.854	47.760	209.083	454.625

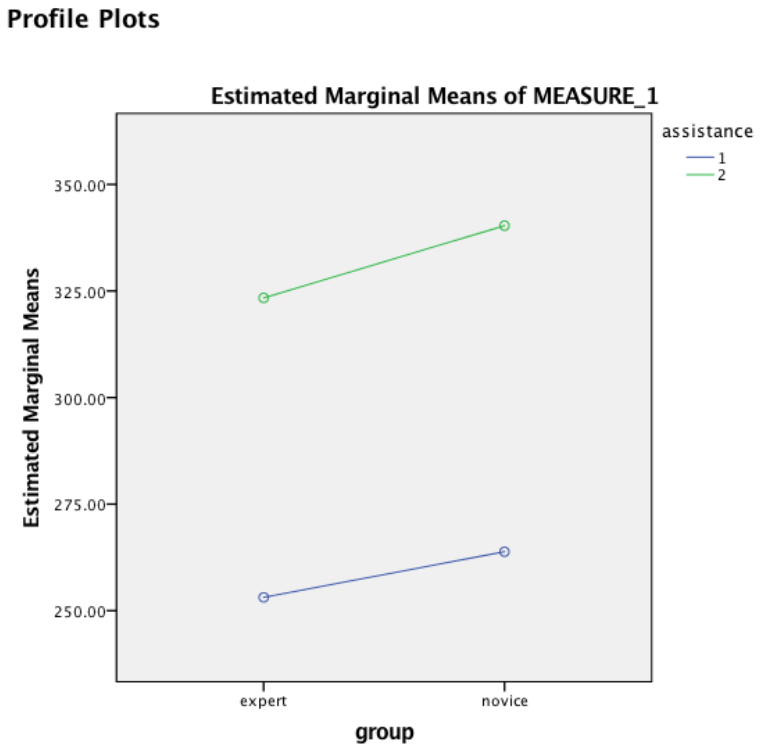
4. group * assistance

Measure: MEASURE_1

group	assistance	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
expert	1	253.125	37.055	157.873	348.377
	2	323.375	62.533	162.630	484.120
novice	1	263.833	42.787	153.846	373.821
	2	340.333	72.206	154.721	525.946

Results

Efficiency (time not including timeouts)



Results

Workload (TLX)

Within-Subjects Factors

Measure: MEASURE_1

assistance	Dependent Variable
1	cogaid_tlx
2	nocogaid_tlx

Between-Subjects Factors

		Value Label	N
group	0	expert	4
	1	novice	4

Descriptive Statistics

	group	Mean	Std. Deviation	N
cogaid_tlx	expert	40.0463	29.53423	4
	novice	37.5000	18.73714	4
	Total	38.7731	22.93787	8
nocogaid_tlx	expert	42.4769	18.90933	4
	novice	42.3611	18.68941	4
	Total	42.4190	17.40524	8

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
assistance	Sphericity Assumed	53.169	1	53.169	.268	.623	.268	.072
	Greenhouse-Geisser	53.169	1.000	53.169	.268	.623	.268	.072
	Huynh-Feldt	53.169	1.000	53.169	.268	.623	.268	.072
	Lower-bound	53.169	1.000	53.169	.268	.623	.268	.072
assistance * group	Sphericity Assumed	5.908	1	5.908	.030	.869	.030	.052
	Greenhouse-Geisser	5.908	1.000	5.908	.030	.869	.030	.052
	Huynh-Feldt	5.908	1.000	5.908	.030	.869	.030	.052
	Lower-bound	5.908	1.000	5.908	.030	.869	.030	.052
Error(assistance)	Sphericity Assumed	1191.030	6	198.505				
	Greenhouse-Geisser	1191.030	6.000	198.505				
	Huynh-Feldt	1191.030	6.000	198.505				
	Lower-bound	1191.030	6.000	198.505				

a. Computed using alpha = .05

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	assistance	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
assistance	Linear	53.169	1	53.169	.268	.623	.268	.072
assistance * group	Linear	5.908	1	5.908	.030	.869	.030	.052
Error(assistance)	Linear	1191.030	6	198.505				

a. Computed using alpha = .05

Results

Workload (TLX)

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
cogaid_tlx	.389	1	6	.556
nocogaid_tlx	.162	1	6	.701

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + group
Within Subjects Design: assistance

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Intercept	26368.645	1	26368.645	34.397	.001	34.397	.998
group	7.087	1	7.087	.009	.927	.009	.051
Error	4599.595	6	766.599				

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
40.596	6.922	23.659	57.533

2. group

Measure: MEASURE_1

group	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
expert	41.262	9.789	17.309	65.214
novice	39.931	9.789	15.978	63.883

3. assistance

Measure: MEASURE_1

assistance	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	38.773	8.744	17.377	60.169
2	42.419	6.647	26.155	58.683

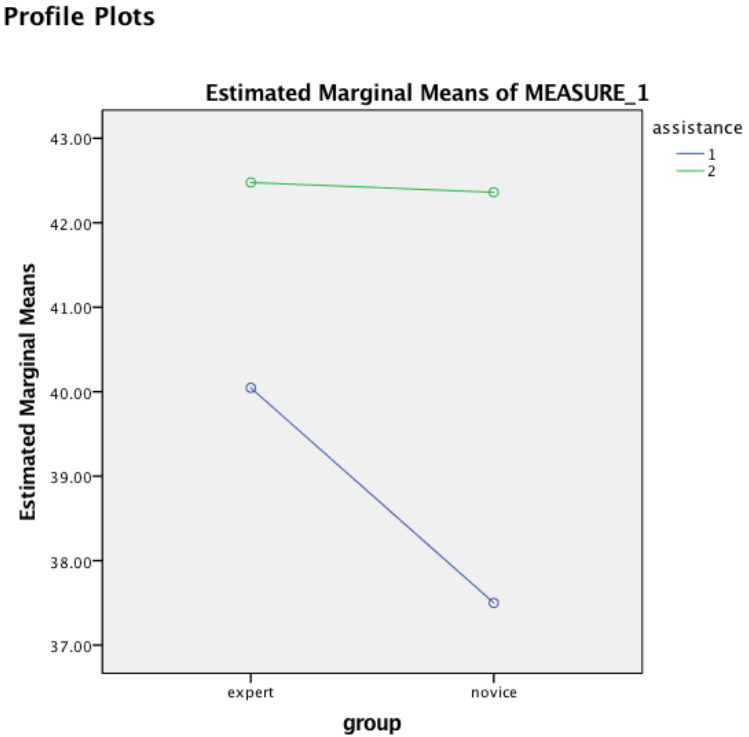
4. group * assistance

Measure: MEASURE_1

group	assistance	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
expert	1	40.046	12.366	9.788	70.305
	2	42.477	9.400	19.476	65.477
novice	1	37.500	12.366	7.241	67.759
	2	42.361	9.400	19.361	65.362

Results

Workload (TLX)



Results

Workload (TLX)

Participant	TLX(100)-1	TLX(21)-1	trans-1	TLX(100)-2	TLX(21)-2	trans-2	TLX(100)-3	TLX(21)-3	trans-3	TLX(100)-4	TLX(21)-4	trans-4	TLX(100)-5	TLX(21)-5	trans-5	TLX(100)-6	TLX(21)-6	trans-6	TLX-Comp.	Scenario#	Trial#	Assistance
301	85	17	15.74074074	35	7	6.481481482	50	10	9.25925926	20	4	3.703703704	4	0	0	20	4	3.703703704	38.88888889	B	1	NoCogAid
301	15	3	2.777777778	15	3	2.777777778	25	5	4.62962963	10	2	1.851851852	15	3	2.777777778	10	2	1.851851852	16.66666667	D	2	NoCogAid
302	75	15	13.88888889	75	15	13.88888889	75	15	13.88888889	0	0	0	75	15	13.88888889	5	1	0.925925926	56.48148149	A	1	NoCogAid
302	65	13	12.03703704	60	12	11.11111111	60	12	11.11111111	15	3	2.777777778	20	4	3.703703704	15	3	2.777777778	43.51851852	C	2	NoCogAid
303	60	12	11.11111111	40	8	7.407407408	45	9	8.333333334	40	8	7.407407408	60	12	11.11111111	55	11	10.18518519	55.55555556	D	3	NoCogAid
303	85	17	15.74074074	70	14	12.96296296	75	15	13.88888889	25	5	4.62962963	75	15	13.88888889	80	16	14.81481482	75.92592593	B	4	NoCogAid
304	15	3	2.777777778	25	5	4.62962963	30	6	5.555555556	20	4	3.703703704	25	5	4.62962963	45	9	8.333333334	29.62962963	C	3	NoCogAid
304	25	5	4.62962963	20	4	3.703703704	20	4	3.703703704	15	3	2.777777778	20	4	3.703703704	25	5	4.62962963	23.14814815	A	4	NoCogAid
311	10	2	1.851851852	10	2	1.851851852	15	3	2.777777778	85	17	15.74074074	45	9	8.333333334	95	19	17.59259259	48.14814815	B	3	NoCogAid
311	45	9	8.333333334	10	2	1.851851852	15	3	2.777777778	45	9	8.333333334	10	2	1.851851852	65	13	12.03703704	35.18518519	D	4	NoCogAid
312	65	13	12.03703704	50	10	9.25925926	50	10	9.25925926	65	13	12.03703704	65	13	12.03703704	45	9	8.333333334	62.96296297	A	3	NoCogAid
312	45	9	8.333333334	50	10	9.25925926	60	12	11.11111111	70	14	12.96296296	55	11	10.18518519	55	11	10.18518519	62.03703704	C	4	NoCogAid
313	30	6	5.555555556	20	4	3.703703704	45	9	8.333333334	25	5	4.62962963	35	7	6.481481482	60	12	11.11111111	39.81481482	D	1	NoCogAid
313	50	10	9.25925926	10	2	1.851851852	60	12	11.11111111	60	12	11.11111111	55	11	10.18518519	65	13	12.03703704	55.55555556	B	2	NoCogAid
314	25	5	4.62962963	0	0	0	35	7	6.481481482	25	5	4.62962963	30	6	5.555555556	15	3	2.777777778	24.07407408	C	1	NoCogAid
314	15	3	2.777777778	0	0	0	5	1	0.925925926	20	4	3.703703704	15	3	2.777777778	5	1	0.925925926	11.11111111	A	2	NoCogAid

Results

Time 2x2x2

Within-Subjects Factors

Measure: MEASURE_1

scenario	assistance	Dependent Variable
1	1	simple_cogaid_time_s
	2	simple_nocogaid_time_s
2	1	complex_cogaid_time_s
	2	complex_nocogaid_time_s

Between-Subjects Factors

		Value Label	N
group	0	expert	4
	1	novice	4

Descriptive Statistics

	group	Mean	Std. Deviation	N
simple_cogaid_time_s	expert	201.0000	95.24355	4
	novice	262.5000	63.40084	4
	Total	231.7500	81.79897	8
simple_nocogaid_time_s	expert	491.2500	217.50000	4
	novice	488.5000	154.68139	4
	Total	489.8750	174.72954	8
complex_cogaid_time_s	expert	305.2500	98.24926	4
	novice	355.5000	164.47999	4
	Total	330.3750	128.26862	8
complex_nocogaid_time_s	expert	364.2500	130.64296	4
	novice	458.2500	201.29311	4
	Total	411.2500	164.93787	8

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Noncent. Parameter	Observed Power[c]
scenario	Pillai's Trace	.007	.040[b]	1.000	6.000	.847	.040	.053
	Wilks' Lambda	.993	.040[b]	1.000	6.000	.847	.040	.053
	Hotelling's Trace	.007	.040[b]	1.000	6.000	.847	.040	.053
	Roy's Largest Root	.007	.040[b]	1.000	6.000	.847	.040	.053
scenario * group	Pillai's Trace	.030	.184[b]	1.000	6.000	.683	.184	.065
	Wilks' Lambda	.970	.184[b]	1.000	6.000	.683	.184	.065
	Hotelling's Trace	.031	.184[b]	1.000	6.000	.683	.184	.065
	Roy's Largest Root	.031	.184[b]	1.000	6.000	.683	.184	.065
assistance	Pillai's Trace	.818	26.970[b]	1.000	6.000	.002	26.970	.989
	Wilks' Lambda	.182	26.970[b]	1.000	6.000	.002	26.970	.989
	Hotelling's Trace	4.495	26.970[b]	1.000	6.000	.002	26.970	.989
	Roy's Largest Root	4.495	26.970[b]	1.000	6.000	.002	26.970	.989
assistance * group	Pillai's Trace	.004	.025[b]	1.000	6.000	.880	.025	.052
	Wilks' Lambda	.996	.025[b]	1.000	6.000	.880	.025	.052
	Hotelling's Trace	.004	.025[b]	1.000	6.000	.880	.025	.052
	Roy's Largest Root	.004	.025[b]	1.000	6.000	.880	.025	.052
scenario * assistance	Pillai's Trace	.246	1.956[b]	1.000	6.000	.211	1.956	.219
	Wilks' Lambda	.754	1.956[b]	1.000	6.000	.211	1.956	.219
	Hotelling's Trace	.326	1.956[b]	1.000	6.000	.211	1.956	.219
	Roy's Largest Root	.326	1.956[b]	1.000	6.000	.211	1.956	.219
scenario * assistance * group	Pillai's Trace	.029	.182[b]	1.000	6.000	.685	.182	.065
	Wilks' Lambda	.971	.182[b]	1.000	6.000	.685	.182	.065
	Hotelling's Trace	.030	.182[b]	1.000	6.000	.685	.182	.065
	Roy's Largest Root	.030	.182[b]	1.000	6.000	.685	.182	.065

a. Design: Intercept + group
Within Subjects Design: scenario + assistance + scenario * assistance

b. Exact statistic

c. Computed using alpha = .05

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Epsilon[b] Huynh-Feldt	Epsilon[b] Lower-bound
scenario	1.000	.000	0	.	1.000	1.000	1.000
assistance	1.000	.000	0	.	1.000	1.000	1.000
scenario * assistance	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept + group
Within Subjects Design: scenario + assistance + scenario * assistance

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
scenario	Sphericity Assumed	800.000	1	800.000	.040	.847	.040	.053
	Greenhouse-Geisser	800.000	1.000	800.000	.040	.847	.040	.053
	Huynh-Feldt	800.000	1.000	800.000	.040	.847	.040	.053
	Lower-bound	800.000	1.000	800.000	.040	.847	.040	.053
scenario * group	Sphericity Assumed	3655.125	1	3655.125	.184	.683	.184	.065
	Greenhouse-Geisser	3655.125	1.000	3655.125	.184	.683	.184	.065
	Huynh-Feldt	3655.125	1.000	3655.125	.184	.683	.184	.065
	Lower-bound	3655.125	1.000	3655.125	.184	.683	.184	.065
Error(scenario)	Sphericity Assumed	118896.375	6	19816.063				
	Greenhouse-Geisser	118896.375	6.000	19816.063				
	Huynh-Feldt	118896.375	6.000	19816.063				
	Lower-bound	118896.375	6.000	19816.063				
assistance	Sphericity Assumed	229842.000	1	229842.000	26.970	.002	26.970	.989
	Greenhouse-Geisser	229842.000	1.000	229842.000	26.970	.002	26.970	.989
	Huynh-Feldt	229842.000	1.000	229842.000	26.970	.002	26.970	.989
	Lower-bound	229842.000	1.000	229842.000	26.970	.002	26.970	.989
assistance * group	Sphericity Assumed	210.125	1	210.125	.025	.880	.025	.052
	Greenhouse-Geisser	210.125	1.000	210.125	.025	.880	.025	.052
	Huynh-Feldt	210.125	1.000	210.125	.025	.880	.025	.052
	Lower-bound	210.125	1.000	210.125	.025	.880	.025	.052
Error(assistance)	Sphericity Assumed	51133.375	6	8522.229				
	Greenhouse-Geisser	51133.375	6.000	8522.229				
	Huynh-Feldt	51133.375	6.000	8522.229				
	Lower-bound	51133.375	6.000	8522.229				
scenario * assistance	Sphericity Assumed	62835.125	1	62835.125	1.956	.211	1.956	.219
	Greenhouse-Geisser	62835.125	1.000	62835.125	1.956	.211	1.956	.219
	Huynh-Feldt	62835.125	1.000	62835.125	1.956	.211	1.956	.219
	Lower-bound	62835.125	1.000	62835.125	1.956	.211	1.956	.219
scenario * assistance * group	Sphericity Assumed	5832.000	1	5832.000	.182	.685	.182	.065
	Greenhouse-Geisser	5832.000	1.000	5832.000	.182	.685	.182	.065
	Huynh-Feldt	5832.000	1.000	5832.000	.182	.685	.182	.065
	Lower-bound	5832.000	1.000	5832.000	.182	.685	.182	.065
Error (scenario*assistance)	Sphericity Assumed	192714.375	6	32119.063				
	Greenhouse-Geisser	192714.375	6.000	32119.063				
	Huynh-Feldt	192714.375	6.000	32119.063				
	Lower-bound	192714.375	6.000	32119.063				

a. Computed using alpha = .05

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	scenario	assistance	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
scenario	Linear		800.000	1	800.000	.040	.847	.040	.053
scenario * group	Linear		3655.125	1	3655.125	.184	.683	.184	.065
Error(scenario)	Linear		118896.375	6	19816.063				
assistance		Linear	229842.000	1	229842.000	26.970	.002	26.970	.989
assistance * group		Linear	210.125	1	210.125	.025	.880	.025	.052
Error(assistance)		Linear	51133.375	6	8522.229				
scenario * assistance	Linear	Linear	62835.125	1	62835.125	1.956	.211	1.956	.219
scenario * assistance * group	Linear	Linear	5832.000	1	5832.000	.182	.685	.182	.065
Error (scenario*assistance)	Linear	Linear	192714.375	6	32119.063				

a. Computed using alpha = .05

Results

Time 2x2x2

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Noncent. Parameter	Observed Power[b]
Pillai's trace	.818	26.970[a]	1.000	6.000	.002	26.970	.989
Wilks' lambda	.182	26.970[a]	1.000	6.000	.002	26.970	.989
Hotelling's trace	4.495	26.970[a]	1.000	6.000	.002	26.970	.989
Roy's largest root	4.495	26.970[a]	1.000	6.000	.002	26.970	.989

Each F tests the multivariate effect of assistance. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

Levene's Test of Equality of Error Variances[a]

	F	df1	df2	Sig.
simple_cogaid_time_s	.246	1	6	.638
simple_nocogaid_time_s	.556	1	6	.484
complex_cogaid_time_s	1.159	1	6	.323
complex_nocogaid_time_s	.282	1	6	.614

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + group
Within Subjects Design: scenario + assistance + scenario * assistance

4. scenario * assistance

Measure: MEASURE_1

scenario	assistance	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	1	231.750	28.604	161.759	301.741
	2	489.875	66.724	326.608	653.142
2	1	330.375	47.897	213.174	447.576
	2	411.250	59.993	264.452	558.048

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Intercept	4282201.12	1	4282201.12	148.425	.000	148.425	1.000
group	20604.500	1	20604.500	.714	.430	.714	.111
Error	173105.875	6	28850.979				

a. Computed using alpha = .05

Estimated Marginal Means

1. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
365.813	30.027	292.340	439.285

scenario

Estimates

Measure: MEASURE_1

enario	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
	360.813	30.797	285.456	436.169
	370.813	45.752	258.861	482.764

Pairwise Comparisons

Measure: MEASURE_1

scenario	(J) scenario	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	95% Confidence Interval for Difference[a] Upper Bound
	2	-10.000	49.770	.847	-131.782	111.782
	1	10.000	49.770	.847	-111.782	131.782

sed on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Noncent. Parameter	Observed Power[b]
ai's trace	.007	.040[a]	1.000	6.000	.847	.040	.053
ks' lambda	.993	.040[a]	1.000	6.000	.847	.040	.053
telling's trace	.007	.040[a]	1.000	6.000	.847	.040	.053
y's largest root	.007	.040[a]	1.000	6.000	.847	.040	.053

ch F tests the multivariate effect of scenario. These tests are based on the linearly independent pairwise mparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .05

s. assistance

Estimates

Measure: MEASURE_1

assistance	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	281.063	32.895	200.570	361.555
2	450.563	35.408	363.923	537.202

Pairwise Comparisons

Measure: MEASURE_1

(I) assistance	(J) assistance	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	95% Confidence Interval for Difference[b] Upper Bound
1	2	-169.500*	32.639	.002	-249.364	-89.636
2	1	169.500*	32.639	.002	89.636	249.364

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Results

TAM

Participant	Group	TAM PU-1	TAM PU-2	TAM PU-3	TAM PU-4	TAM PU-5	TAM PU-6	Average
301	EXPERT	1	1	2	1	2	1	1.33333333
302	EXPERT	7	7	7	7	7	7	7
303	EXPERT	3	3	3	3	3	2	2.83333333
304	EXPERT	6	6	6	6	6	6	6
311	NOVICE	2	2	5	4	3	4	3.33333333
312	NOVICE	2	2	2	2	2	2	2
313	NOVICE	2	3	3	2	3	3	2.66666667
314	NOVICE	2	2	2	2	2	2	2

1	Extremely Likely
2	Quite Likely
3	Slightly Likely
4	Neither
5	Slightly Unlikely
6	Quite Unlikely
7	Extremely Unlikely

Results

Misc

Average of NASA TLX	Column Labels						
	Expert		Expert Total	Novice		Novice Total	Grand Total
Row Labels	CogAid	NoCogAid		CogAid	NoCogAid		
ACE	29.62962963	36.57407408	33.10185185	45.83333334	43.05555556	44.44444445	38.77314815
JNO	59.72222223	57.40740741	58.56481482	29.62962963	51.85185186	40.74074074	49.65277778
MRO	53.70370371	36.11111111	44.90740741	34.72222223	37.5	36.11111111	40.50925926
VGR2	17.12962963	39.81481482	28.47222222	39.81481482	37.03703704	38.42592593	33.44907408
Grand Total	**40.0462963**	**42.47685186**	**41.26157408**	**37.5**	**42.36111111**	**39.93055556**	**40.59606482**

Average of Total Time (s)	Column Labels						
	Expert		Expert Total	Novice		Novice Total	Grand Total
Row Labels	CogAid	NoCogAid		CogAid	NoCogAid		
ACE	310.5	475.5	393	428	530	479	436
JNO	262.5	600	431.25	280	600	440	435.625
MRO	300	253	276.5	283	386.5	334.75	305.625
VGR2	139.5	382.5	261	245	377	311	286
Grand Total	**253.125**	**427.75**	**340.4375**	**309**	**473.375**	**391.1875**	**365.8125**

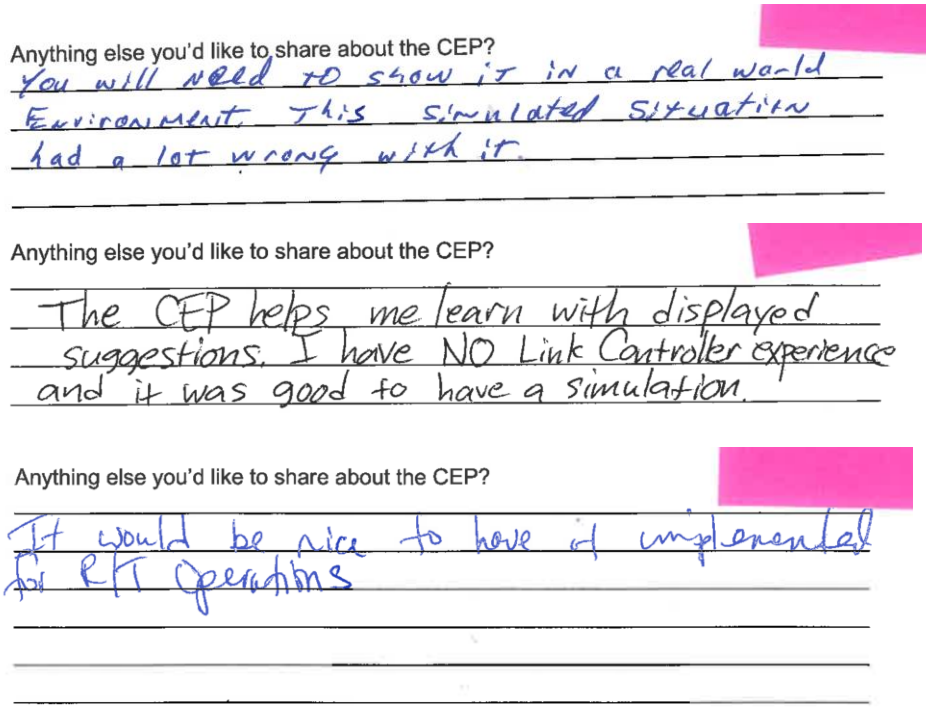
	Column Labels		
	Expert	Novice	Grand Total
Average of cogaid_prompt_clicks	**2.375**	**2.125**	**2.25**

Participant	Group	cogaid_prompt_clicks
301	Expert	3.5
302	Expert	0.5
303	Expert	3
304	Expert	2.5
311	Novice	2
312	Novice	3
313	Novice	1.5
314	Novice	2

ExpAgeAv	NovAgeAv		ExpFem	NovFem	ExpMal	NovMal
58.75	46		2	1	2	3
ExpWorkYrAv	NovWorkYrAv					
30.5yr	2.75yr					

Results

Participant Feedback



Anything else you'd like to share about the CEP?

You will need to show it in a real world Environment. This simulated situation had a lot wrong with it.

Anything else you'd like to share about the CEP?

The CEP helps me learn with displayed suggestions. I have NO Link Controller experience and it was good to have a simulation.

Anything else you'd like to share about the CEP?

It would be nice to have it implemented for RT Operations

Results

Participant Feedback

Anything else you'd like to share about the CEP?

The CEP would be useful to new operator as getting Testing and ~~Evaluate~~ Operator's ability to comp with the ~~low~~ stress and if comfort of the job.

Anything else you'd like to share about the CEP?

as it improves over Time it may mature enough to be usefull

Anything else you'd like to share about the CEP?

"There is utility in technology, but it has to capture every possible instance."

Anything else you'd like to share about the CEP?

SOME FEEDBACK AS TO WHAT MONITOR ITEMS ARE BEING ANALYSED TO DETERMINE SUGGESTED ACTIONS. CONFIRM WHICH PERFORMANCE PARAMETERS HAVE BEEN CHECKED BY CEP AND DEEMED NOMINAL.

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Backup Slides

Background

Cognitive Aids

- The National Playbook (Playbook, 2017)
  - Collection of about 130 plays
  - Air traffic controllers (ATCos) use it to re-route traffic flows
  - ATCos combine spatial factors with their knowledge of play success rate and play implications

Background

Cognitive Aids

- Playmaker (Allendoerfer & Weber, 2004)
  - Decision support aid for air traffic management
  - Made recommendations like ATCos using machine learning
  - ATCo recommendation matched Playbook recommendation in four of six scenarios
  - Little understanding of its impact

Method

Task

- Track Configuration Information
- Spacecraft: VOYAGER 2
- Antenna: DSS 43
- Antenna Location: Canberra
- Weather Forecast: Light rains imminent
- Predict Mode: 1W
- Command State: Tracking
- Conscan: Disabled
- Band: X-band
- Rainblower: Off