Perception, Cognition, Action

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Our Research Approach

Validated Design knowledge

requirements

statistics

empirical validation

assessment criteria

Interactive systems

User’s visual Attention Focus


The relative ratios of the user's visual focus looking expectantly on one of the four quadrants of a dark and unstructured computer screen.

<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>40%</td>
<td>20%</td>
</tr>
<tr>
<td>25%</td>
<td>15%</td>
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</tbody>
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MSc Thesis (1993) from Christian Cachin

Signal Detection Experiment

N = 19; 11 women and 8 men took part in the experiment (mean age: 33 ± 14 years). 12 subjects were students of computer science at the ETH.

Dual task approach: (1) count circles, (2) detect signal X (given a distractor [])

Standard computer display: 14 inch, black&white
Results: primary task

‘Circle Deviation’ CD as a measure for task accuracy:

\[ CD = \frac{|#\text{CIRCLES}_{\text{counted}} - #\text{CIRCLES}_{\text{presented}}| \times 100\%}{#\text{CIRCLES}_{\text{presented}}} \]

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
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<tbody>
<tr>
<td>CD</td>
<td>6.1%</td>
<td>6.8%</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>III</th>
<th>IV</th>
</tr>
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<tbody>
<tr>
<td>CD</td>
<td>6.9%</td>
<td>4.4%</td>
</tr>
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</table>

Main Results:
Quadrant IV outperforms all others
Results: secondary task

Signal Detection Table:

<table>
<thead>
<tr>
<th>answer of the subject</th>
<th>NO</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>YES</td>
<td>c</td>
<td>d</td>
</tr>
</tbody>
</table>

NO X SIGN (nothing or square) | X SIGN PRESENTED

‘Error Ratio’ ER:
ER = (b + c) / (a + d) * 100%

Error Ratio (%) vs Distance (inch)

[X] vs [no signal or square]
[X] vs [no signal]
Eye Recording Experiment

How to determine automatically the actual position of the user’s visual attention focus on a computer screen?

Subjects:
N=6: 2 women and 4 men
5 subjects were students of computer science at the ETH. 1 subject studied psychology at Uni Zurich.

Tasks:
(1) Computer game;
(2) Text formatting;
(3) Hypertext navigation.

Main Results:
(1) without mouse operations:
Mouse position in fixation region for 25% - 70%

(2) with mouse operations:
Mouse position in fixation region for 49% - 97%

[fixation region: circle around fixation point with r=3 inch]
Validated Design Recommendations

(1) Place the message left above the actual user’s focus of attention;
(2) Place this message maximal 3 inch away of actual mouse position.
Automatic Mental Model Evaluation

Perception, Cognition, Action


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Net Complexity Metrics

Stevens, Myers and Constantine (1974):

\[ C_{\text{state}} = S \]
\[ C_{\text{fan}} = T / S \]

McCabe (1976):

\[ C_{\text{cycle}} = T - S + P \quad \text{[with } P=1\text{]} \]

Kornwachs (1987):

\[ C_{\text{density}} = T / (S^*(S-1)) \]

Validation study:

\( C_{\text{cycle}} \) from McCabe outperforms all other metrics!

Simple Petri Net:

- \( T = \) number of transitions
- \( S = \) number of states

Results

Experiment:
N=6 novices; N=6 experts
4 tasks with a database
Metric BC=C_{cycle}

We found a negative correlation between
Behavior-Complexity BC and [assumed] Cognitive-Complexity CC

Possible Conclusion

"dales": knowledge about successful behavior

"wall": knowledge about unsuccessful behavior

This conclusion would have major impact e.g. on training procedures of operators of complex systems!

Tangible User Interfaces…

The Build-It System

3D Interaction Props

**Task:**
locate disk (with variable diameter and thickness) in neck of phantom aneurysm and align RISP over it.

**RISP:**
Rigid Intersection Selection Prop

Different RISP designs


Napier (1956) classified grips into 2 different categories
'precision grip' and 'power grip'.
Assessment via Coordination Measures

[Ergonomics]
When using a physical 2D and 3D input device the user should produce well-coordinated movements.

[Medicine]
Surgical success depends on the controlled and orchestrated use of the appropriate instrument.

How to assess the ergonomic quality of different input devices?

**Existing Measures-1**

Multiplicative combination of 4 Dimensions of Performance (DOP) 
(1) speed, (2) smoothness, (3) volume appropriateness and (4) accuracy.

\[ \text{speed} = \frac{\text{distance}}{\text{time}} \quad \text{smoothness} = \frac{1}{|\text{jerk}_x| \times |\text{jerk}_y| \times |\text{jerk}_z|} \]

\[ \text{jerk}_x = \frac{(X_2 - X_1) - (X_1 - X_0)) - ((X_3 - X_2) - (X_2 - X_1))}{\Delta t^3} \]

\[ \text{Volume}_{\text{appropriateness}} = RA_x \times RA_y \times RA_z \]

\[ RA_x = \frac{1}{|\text{appropriate\_range}_x - \text{measured\_range\_used}_x|} \]

\[ \text{Accuracy} = \text{average}_{over\ j}(\frac{1}{\text{error}_j}) \]

\[ \text{error}_{\text{targ}, j} = \text{min}_{over\ i}(\sqrt{(x_i - x_{\text{targ}, j})^2 + (y_i - y_{\text{targ}, j})^2 + (z_i - z_{\text{targ}, j})^2}) \]

Empirical validation with clinical experts showed:
Smoothness: lowest correlation
Speed x Accuracy: highest correlation

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Existing Measures-2

NeuroMotor Channel Capacity metric NMCC is based on Fitts' law:

\[ MT = a + b \log_2 \left( \frac{2A}{W} \right) \]

The ‘Index of Performance' IP = 1/b (in bits/sec) is used as the NMCC.

This 1D measure correlated well with known effects of age, handedness, gender, etc. on coordination drawn from a questionnaire surveying physical therapists' perception of “coordination”. But, no explicit definition of ‘coordination’ is given.

Existing Measures-3 and -4


**Inefficiency Metric (IM):**

\[
l = \frac{\text{Length of Actual path} - \text{Length of shortest path}}{\text{Length of Short path}}
\]

\[
r = \frac{\text{Amount of actual rotation} - \text{Initial rotation mismatch}}{\text{Initial rotation mismatch}}
\]

\[
r = \frac{\phi_B - \phi_A}{\phi_A}
\]


**M-Metric:**

\[
m = (\text{simultaneity of control “SOC”}) \times (\text{efficiency of control “EFF”})
\]

\[
SOC = \int_0^T \text{Min}(NERF}_1(t), NERF}_2(t) \ldots NERF}_n(t)\text{dt},
\]

\[
EFF = \sum_{i=1}^n (W_i \times \frac{OPT}_i}{ACT}_i)
\]
# Assessment of the different Metrics

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<tbody>
<tr>
<td>(R1) trajectory based – spatial characteristic to complement time</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>(R2) compare the actual path with an optimal path.</td>
<td>yes</td>
<td>no</td>
<td>no*</td>
<td>no*</td>
</tr>
<tr>
<td>[The optimal path should depend on the current and target position.]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(R3) independent of coordinate-system and sampling rate</td>
<td>yes²</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>(R4) applicable (or extendable) to rigid body positioning and rotation, and</td>
<td>no</td>
<td>no</td>
<td>yes¹</td>
<td>yes¹</td>
</tr>
<tr>
<td>potentially also to scaling</td>
<td></td>
<td></td>
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Remarks:

No* - The optimal path does not depend on the current point.
Yes¹ - No measure proposed for scaling.
Yes² - The smoothness and volume appropriateness measures proposed is coordinate-system dependent.
Proposed Instantaneous Coordination

If angle $\theta$ exceeds a given maximum angle $\theta_{\text{max}}$ then instantaneous coordination is 0.

**COSINE** of angle $\theta$ between (AC) and (AB) determines the Instantaneous **Coordination** at A.
Instantaneous Coordination $C_{m-1}$

Based on Binsted et al. (2001) we assume that points earlier in the path have a larger effect on perceived coordination than points closer to the target.

$$C_{m-1} = \max\left[\frac{\cos \theta_{m-1} - \cos \theta_{\max}(m)}{1 - \cos \theta_{\max}(m)}, 0\right]$$

$\theta_{\max}$ vary with path length:

$$\theta_{\max}(m) = \theta_1 - \theta_2 l(m)$$

Path length: $l(m) = \sum_{i=1}^{m} d_{i-1,i}$

**Overall Coordination**

via Minkowski metric with exponent $P$ [0.1 < $P$ < 1.0]

$$C = \left[\frac{\sum_{m-1}^{P} d_{m-1,m}}{\sum_{m} d_{m-1,m}}\right]^{\frac{1}{P}}$$

Validation experiment: 10 different user paths

Path 1

Path 2

Path 3

Path 4

Path 5

Path 7

Path 8
MDS Results: subjective scores

11 subjects (8 males, 3 females) were shown all 10 paths and were asked to rank them from most coordinated (+2) to least coordinated (-2)

Results:
Path-7 most coordinated
Path-3 least coordinated

Results for overall Coordination

With varying parameters $\theta_1$, $\theta_2$ and $P$

X-axis: results of measures $C$, IM (Ineff), and m-Metric

Y-axis: Difference $d$ between objective measure ($X$) and subjective scores ($S$)

$(\theta_1, \theta_2)$

exponent $P$:

$0.1 < P < 1.0$

by steps of 0.1

$(30,10)$
$(35,10)$
$(40,20)$
$(45,25)$
$(50,30)$
$(55,35)$
$(60,40)$

(with $P=0.3; \ r=0.97$)

Differences shown as distance:

$$d = 1 - r^2_{xs}$$

$$r_{xs} = \frac{C(X, S)}{\sqrt{C(X, X)C(S, S)}}$$

$$C(X, S) = \frac{1}{n} \sum_{j=0}^{n} (X_i - \bar{X})(S_i - \bar{S})$$
Discussion

One outcome of our experiment shows that people do indeed share an intuitive understanding of the term "coordination".

The $m$-metric has high correlation with the subjective scores, but does not satisfy R3: independence of coordinate system!

The computational theory for our metric C seems to accurately predict subjective impressions on coordination, and satisfies all 4 requirements!
Future Directions…

Further validation studies:
Correlations with ranking schemes based on clinical experts (patients traces and their ranks are based on the observation of the global movement path)

Correlations between performance time and other 3D task characteristics.

And how to analyze human behavior in 3D space & time over a couple of days?
Thank you for your attention.