WCST analysis

Check data

The size of the raw data table is (number of moves x number of variables):

```
## [1] 269  11
```

There should be 4 types of rules: c, n, s and spxxxx (x stands for A, B, C or D). If there is more than 4, calculations based on the rules will be wrong!

```
##      c      n      s spABCD
##     40     52     60    117
```

There should be 24+1=25 types of source cards if we use unambiguous cards or 64-4+1=61 types if we use ambiguous cards. The number of source card types:

```
## [1] 61
```

All source cards should have a 4-digit code. The source card codes and frequencies were:

```
## cg1 cy1 cy4 qb1 qg1 qy4 sb3 sb4 sg3 sg4 sr1 sy1 tg2 tg3 tr2 ty1 ty3 cb3
##   5   2   3   5   3   4   5   3   3   4   3   3   4   6   4   3   6   6
## cg4 qb2 qg4 qr2 wh5 cb1 cg3 cr1 cr2 cr3 cy2 cy3 qb3 qb4 qg2 qg3 qr1 qr3
##   3   3   3   5  79   3   3   2   4   3   7   2   4   2   2   2   2   3
## qr4 qy1 qy2 sb1 sb2 sg1 sr3 sr4 sy2 sy3 tb1 tb2 tb4 tg1 tg4 tr3 tr4 ty4
##   2   3   2   3   3   4   2   4   2   5   4   2   3   4   2   3   3   3
## cb2 cg2 cr4 sr2 sy4 tb3 ty2
##   2   1   2   2   1   1   2
```

There should be 4 types of target cards, with the codes: tr1A, sg2B, qy3C, cb4D. Target card codes and frequencies were:

```
##          cb4D          qy3C          sg2B          tr1A div1undefined
##            51            97            72            48             1
```

Variables

Additional variables per move

From the raw data, I calculated some additional variables, such as:

- Think time: total time between two drop action minus the time spent with drag-and-drop
- Current rule: this is the same as "category", but recoded with numbers, where s, c, n and sp have the codes: 1, 2, 3 and 4, respectively.
- Applied rule: the rule that the move conforms to. THIS WON'T BE CORRECT UNTIL THE SOURCE CARD CODE DOES NOT INCLUDE THE INDEX FOR THE SPATIAL RULE

- Number of applied rules: integer from 0 to 4 (actually 3, because we excluded the key cards from the deck)
- Random search: this is TRUE if none of the rules applies to the current rule (if the number of applied rules = 1)
- Perseveration error: after a "success", we check if the participant keeps using the same rule (if the applied rule - or one of the applied rules - is the same as the current rule in the successful step) for any number of moves

An example: Data for participant 242040

```
## [1] tar_card     src_card     match        current_rule applied_rule
## [6] randsearch   persev
## <0 rows> (or 0-length row.names)
```

Variables per participant

From the per-move variables, I calculated averaged and summed values for each participant, separately for each rule:

- success
- failure
- number of moves
- number of correct moves
- number of incorrect moves
- average time between two drop actions
- average move time
- average think time
- time spent with the task (sec)

```
## Source: local data frame [29 x 6]
## Groups: condition, part [8]
##
##    condition   part category success_bin failure_bin moves_nb
##       (fctr)  (int)   (fctr)       (int)       (int)    (dbl)
## 1      wcstf 178897        c           0           0        3
## 2      wcstf 178897        n           0           1        3
## 3      wcstf 178897        s           0           1        3
## 4      wcstf 178897   spABCD           0           1        9
## 5     wcstfc 259228        c           0           1        3
## 6     wcstfc 259228        n           0           0        3
## 7     wcstfc 259228        s           0           1        3
## 8     wcstfc 259228   spABCD           0           1        9
## 9     wcstfc 762799        c           1           0        8
## 10    wcstfc 762799        n           1           0        8
## ..       ...    ...      ...         ...         ...      ...
```

```
## Source: local data frame [29 x 6]
##
##    correctmoves_nb incorrectmoves_nb totaltime_avg movetime_avg
##              (int)             (int)         (dbl)        (dbl)
## 1                1                 1      1748.000     792.0000
## 2                1                 2      1562.333     650.0000
```

```
## 3                1                2      1926.000     885.0000
## 4                2                7      2034.000     858.4444
## 5                0                3      2181.000     521.6667
## 6                1                1      1757.000     802.5000
## 7                2                1      1612.000     611.0000
## 8                1                8      1825.667     646.0000
## 9                8                0      4605.750    2035.1250
## 10               7                1      3155.875    1613.1250
## ..             ...              ...           ...          ...
## Variables not shown: thinktime_avg (dbl), time_spent (dbl)
```

- *Would perseveration be interesting? Do we need it?*
- *Distribution of rules used?*

Variables per condition

I coded the following variables, separately for each rule:

- Number of participants
- Number of solvers
- Number of nonsolvers
- Percentage of solvers
- Average number of moves
- Average time spent with the task

Other ideas?

```
## Source: local data frame [16 x 6]
## Groups: condition [4]
##
##    condition category partic_nb solvers_nb nonsolvers_nb solvers_perc
##       (fctr)   (fctr)     (int)      (int)         (int)        (dbl)
## 1      wcstf        c         0          0             0           NA
## 2      wcstf        n         1          0             1      0.00000
## 3      wcstf        s         1          0             1      0.00000
## 4      wcstf   spABCD         1          0             1      0.00000
## 5     wcstfc        c         2          1             1     50.00000
## 6     wcstfc        n         1          1             0    100.00000
## 7     wcstfc        s         1          0             1      0.00000
## 8     wcstfc   spABCD         2          1             1     50.00000
## 9      wcstc        c         3          1             2     33.33333
## 10     wcstc        n         3          1             2     33.33333
## 11     wcstc        s         3          1             2     33.33333
## 12     wcstc   spABCD         0          0             0          NaN
## 13      wcst        c         1          1             0    100.00000
## 14      wcst        n         1          1             0    100.00000
## 15      wcst        s         1          1             0    100.00000
## 16      wcst   spABCD         0          0             0          NaN
```

```
## Source: local data frame [16 x 2]
##
##    nbofmoves_avg timespsent_avg
```

```
##            (dbl)          (dbl)
## 1       3.000000        3.49600
## 2       3.000000        4.68700
## 3       3.000000        5.77800
## 4       9.000000       18.30600
## 5       5.500000       21.69450
## 6       5.500000       14.38050
## 7      10.000000       23.60800
## 8      23.000000      153.57000
## 9       5.333333       11.56267
## 10      8.666667       20.02733
## 11      8.000000       16.83700
## 12     12.000000       19.98400
## 13     11.000000       22.56600
## 14      7.000000       15.70850
## 15     14.000000       31.35700
## 16     30.000000      155.06700
```

Hypotheses

In our plans we had the following testable hypotheses:

1. Going through the standard rules first makes the task of finding the index rule harder
    a) Condition 1 (WCST) will be more difficult than condition 2 (WCSTF)
    b) Condition 3 (WCSTC) will be more difficult than condition 4 (WCSTFC)
    c) Condition 1 (WCST) will be more difficult than condition 4 (WCSTFC)
2. Using the standard cards for the index rule makes the task of finding the index rule harder
    a) Condition 1 (WCST) will be more difficult than condition 3 (WCSTC)
    b) Condition 2 (WCSTF) will be more difficult than condition 4 (WCSTFC)
    c) Condition 1 (WCST) will be more difficult than condition 4 (WCSTFC)
3. Some participants will report having an Heureka! moment, so this task can be categorized as an insight task
4. Is impasse associated with inactivity in this task? Is the average move time longer for the spatial task than for the other tasks?

Would you like to add something else? Can we justify Hypothesis 1/c and 2/c?

Analyses

Exclusion of participants

What exclusion criteria do we want to use?

- Exclude participants who did not finish the experiment?
- Exclude participants who did not find out the standard rules?
- Exclude participants who stay inactive for more than a certain amount of time?
- Exclude participants who respond too quickly?

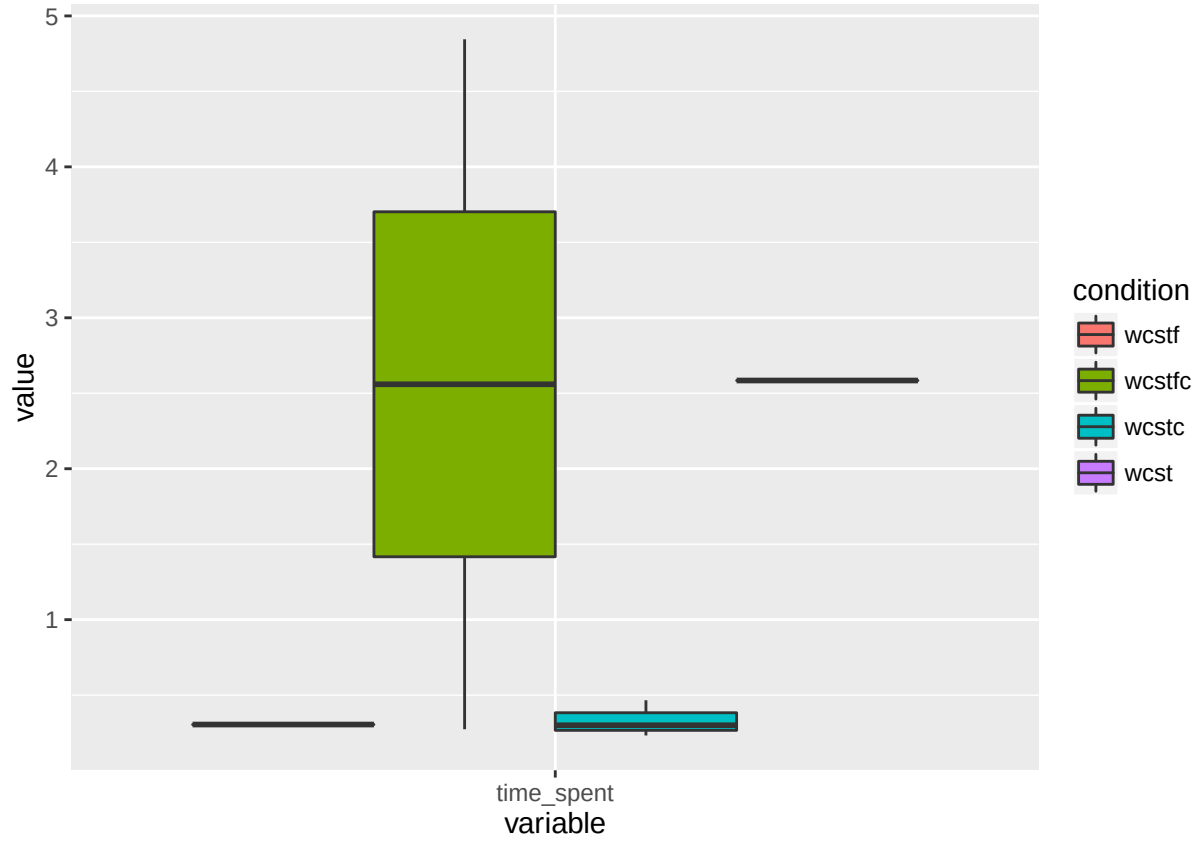
Statistical tests

For deciding whether solving the task in one condition is more difficult than solving it in another, we can use two variables: solution rates and solution times. As for the solution rates, we can construct a four-by-two contingency table (number of solvers and non-solvers in the four conditions). Analyzing a larger than two-by-two contingency table is possible with a Chi-square test, but it is only useful if the categories defining the rows are arranged in a natural order with equal spacing between rows. This is not true in our case, so we will have to analyze two-by-two contingency tables instead, separately for Hypothesis 1 and Hypothesis 2. We chose Fisher's exact test, which is supposed to be more exact than the Chi-square test, especially if the cells in the contingency table contain small values.

Solution rates in the four conditions:

```
## Source: local data frame [4 x 3]
## Groups: condition [4]
##
##   condition solvers_nb nonsolvers_nb
##      (fctr)      (int)         (int)
## 1     wcstf          0             1
## 2    wcstfc          1             1
## 3     wcstc          0             0
## 4      wcst          0             0
```

Solution time is calculated for each participant as the time spent with trying to solve the sequence rule (in minutes). We analyzed the solution time with a two-way ANOVA. Median solution times for the four conditions are shown by the box plots in the following figure:



Number of solvers

Does the order of rules influence the difficulty of finding the sequence rule?

We analyzed the contingency table containing the number of solvers and non-solvers in condition WCST and WCSTF and then separately, for condition WCSTC and WCSTFC. A $p<0.05$ means that the row/column association is statistically significant.

```
##
##  Fisher's Exact Test for Count Data
##
## data:  SR1234[c(1, 3), c(2, 3)]
## p-value = 1
## alternative hypothesis: true odds ratio is not equal to 1
## 95 percent confidence interval:
##    0 Inf
## sample estimates:
## odds ratio
##          0
```

```
##
##  Fisher's Exact Test for Count Data
##
## data:  SR1234[c(2, 4), c(2, 3)]
## p-value = 1
## alternative hypothesis: true odds ratio is not equal to 1
## 95 percent confidence interval:
##    0 Inf
## sample estimates:
## odds ratio
##          0
```

Does the order of rules influence the difficulty of finding the sequence rule?

We analyzed the contingency table containing the number of solvers and non-solvers in condition WCST and WCSTC and then separately, for condition WCSTF and WCSTFC. A $p<0.05$ means that the row/column association is statistically significant.

```
##
##  Fisher's Exact Test for Count Data
##
## data:  SR1234[c(1, 2), c(2, 3)]
## p-value = 1
## alternative hypothesis: true odds ratio is not equal to 1
## 95 percent confidence interval:
##   0.00000 77.90627
## sample estimates:
## odds ratio
##          0
```

```
##
##  Fisher's Exact Test for Count Data
##
```

```
## data:  SR1234[c(3, 4), c(2, 3)]
## p-value = 1
## alternative hypothesis: true odds ratio is not equal to 1
## 95 percent confidence interval:
##    0 Inf
## sample estimates:
## odds ratio
##          0
```

Solution time

We checked whether the data was normally distributed with Kolmogorov-Smirnoff test:

```
##
##  One-sample Kolmogorov-Smirnov test
##
## data:  ST1
## D = 1, p-value < 2.2e-16
## alternative hypothesis: two-sided
```

```
##
##  One-sample Kolmogorov-Smirnov test
##
## data:  ST2
## D = 1, p-value < 2.2e-16
## alternative hypothesis: two-sided
```

```
##
##  One-sample Kolmogorov-Smirnov test
##
## data:  ST3
## D = 1, p-value < 2.2e-16
## alternative hypothesis: two-sided
```

```
##
##  One-sample Kolmogorov-Smirnov test
##
## data:  ST4
## D = 1, p-value < 2.2e-16
## alternative hypothesis: two-sided
```

If the data is normally distributed, we use ANOVA, if it is not, we use Wilcoxon.

```
## Warning in wilcox.test.default(ST1, ST2, alternative = "two.sided", paired
## = FALSE, : Requested conf.level not achievable
```

```
##
##  Wilcoxon rank sum test
##
## data:  ST1 and ST2
## W = 1, p-value = 1
```

```
## alternative hypothesis: true location shift is not equal to 0
## 0 percent confidence interval:
##  488983 488983
## sample estimates:
## difference in location
##                 488983
```