SGC_3A: The Insight Hypothesis

2-Response Rescoring

Amy Rae Fox

Contents

NOTE This notebook is superceded by the 2_sgc3A_scoring.qmd, which includes a partial scoring [-1/q, 1/p] scheme which is eventually used to calculate interpretation subscores. This notebook, alternatively, relies on partial [-1/n, 1/n]

The purpose of this notebook is to re-score the response accuracy data for the SGC_3A study. This is required because the question type on the graph comprehension task used a 'Multiple Answer Multiple Choice' design (MCMA). Warning: this notebook takes several minutes to execute.

Pre-Requisite	Followed By
1_sgc3a_harmonize.Rmd	3_sgc3A_descriptives.Rmd

```
#read datafiles, set mode and term
df_items <- read_rds('data/sgc3a_items.rds')
```

INTRODUCTION

The *graph comprehension task* of study SGC 3A presents readers with a graph, a question, and a series of checkboxes. Participants are instructed to use the graph to answer the question, and respond by selecting all the checkboxes that apply, where each checkbox corresponds to a datapoint in the graph.

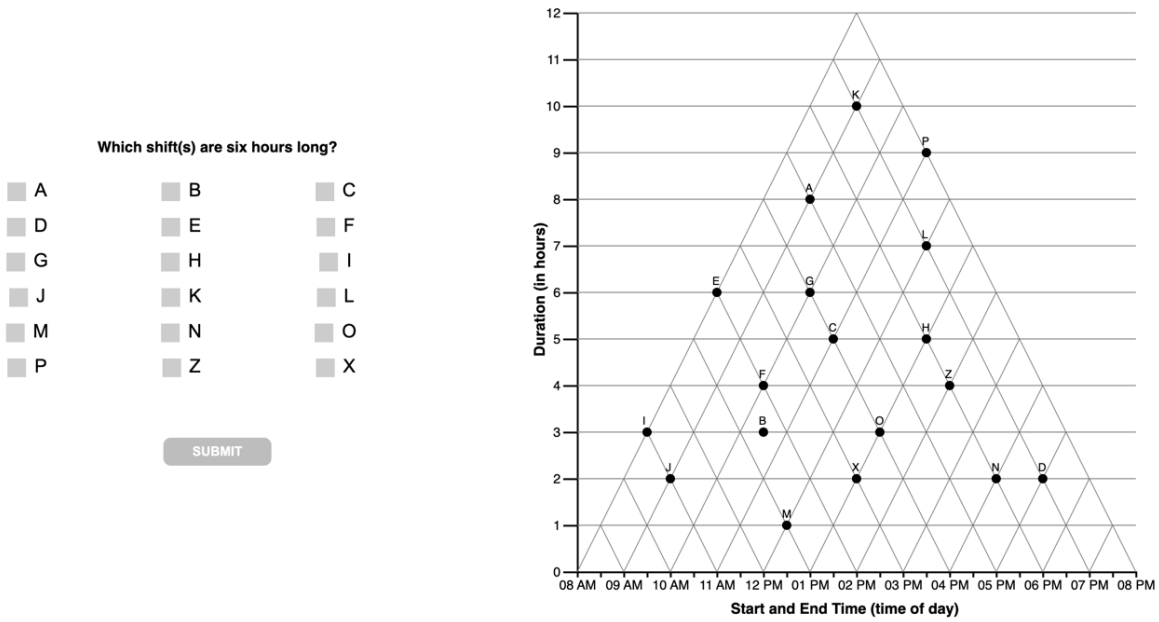


Figure 1: **Figure 1. Sample Graph Comprehension (Question # 6)**

In the psychological and education literatures on Tests & Measures, the format of this type of question is referred to as *Multiple Choice Multiple Answer* (MCMA) or *Multiple Answer Multiple Choice* (MAMC).
It has a number of properties that make it different from traditional *Single Answer Multiple*

Choice (SAMC) questions, where the respondent marks a single response from a number of options In particular, there are a number of very different ways that MAMC questions can be *scored*.

Traditionally in SAMC questions, one point is given for selecting the option designated as correct, and zero points given for marking any of the alternative (i.e. distractor) options. Responses on MAMC questions, however might be partially correct (i), while responses on other answer options within the same item might be incorrect ($n–i$). In MAMC, it is not obvious how to allocate points when the respondent marks a true-correct option (i.e. options that *should* be selected), as well as one or more false-correct options (i.e. options that *should not* be selected). Should partial credit be awarded? If so, are options that respondents false-selected and false-unselected items equally penalized?

Schmidt et. al (2021) performed a systematic literature review of publications proposing MAMC (or equivalent) scoring schemes, ultimately synthesizing over 80sources into 27 distinct scoring approaches. Upon reviewing the benefits of tradeoffs of each approach, for this study we choose utilize two of the schemes: **dichotomous scoring** (Schmidt. et. al scheme #1), and **partial scoring** $[-1/n, 0, +1/n]$ (Schmidt et. al. scheme #17).

The Question Type

First, we acknowledge that the question type evaluated by Schmidt et. al. (2021) is referred to as *Multiple True-False* (MTF), a variant of MAMC where respondents are presented with a question (stem) and series of response options with True/False (e.g. radio buttons) for each. Depending on the implementation of the underlying instrument, it may or may not be possible for respondents to *not respond* to a particular option (i.e. leave the item 'blank'). Although MTF questions have a different underlying implementation (and potentially different psychometric properties) they are identical in their mathematical properties; that is, responses to a MAMC question of 'select all that apply' can be coded as a series of T/F responses to each response option

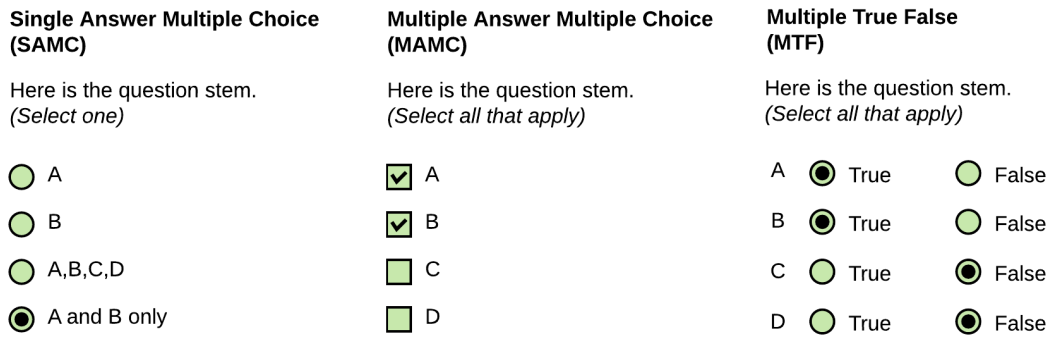


Figure 2: **Figure 2. SAMC (vs) MAMC (vs) MTF**

In this example (Figure 2), we see an example of a question with four response options ($n = 4$) in each question type. In the **SAMC** approach (at left), there are four possible responses, given explictly by the response options (respondent can select only one) ($po_{responses} = n$). With only four options, we cannot entirely discriminate between all of the response variants

we might be interested in, and must always choose an 'ideal subset' of possible distractors to present as response options. In the MAMC (middle) and MTF (at right), the *same number of response options* ($n = 4$) yield a far greater range of responses ($po_{responses} = 2^n$). We can also see the equivalence between a MAMC and MTF format questions with the same response options. Options the respondent *selects* in MAMC are can be coded as **T**, and options they leave *unselected* can be coded as **F**. Thus, for response options (ABCD), a response of [AB] can be encoded as [TTFF].

In our analysis, we will transform the MAMC response string recorded for the participant (given in column `response`), to an MTF encoding.

Scoring Schemes

In the sections that follow, we use the terminology:

$f =$ resulting score
$n =$ number of response options
$i =$ number of *correct responses* by respondent $(0 \leq i \leq n)$
(correct-selected & correct-unselected)

Dichotomous Scoring

Dichotomous Scoring is the strictest scoring scheme, where a response only receives points if it is *exactly* correct, meaning the respondent includes *only true-correct* options, and does select any additional (i.e. true_incorrect) options that should not be selected. This is also known as *all or nothing scoring*, and importantly, it ignores any partial knowledge that a participant may be expressing through their choice of options. They may select some but not all of the true-correct options, and one or more but not all of the false-correct items, but receive the same score as a respondent selects none of the true-correct options, or all of the false-correct options. In this sense, dichotomous scoring tells us only about perfect knowledge, and ignores any indication of partial knowledge the respondent may be indicating.

In Dichotomous Scoring
- question score is either 0 or 1
- full credit is only given if all responses are correct; otherwise; no credit
- does not account for *partial knowledge*. - with increasing number of response options, scoring becomes stricter as each statement must be marked correctly.

The algorithm for **dichotomous scoring** is given by:

$$f = 1, \text{if } i = n0, \text{otherwisewhere } 0 \leq i \leq n \tag{1}$$

```
f_dichom <- function(i, n) {

  # print(paste("i is :",i," n is:",n))

  #if (n == 0 ) return error
  ifelse( (n == 0), print("ERROR n can't be 0"), "")

  #if (i > n ) return error
  ifelse( (i > n), print("i n can't > n"), "")

  #if (i==n) return 1, else 0
```

```
  return (ifelse( (i==n), 1 , 0))

}
```

Partial Scoring [-1/n, +1/n]

Partial Scoring refers to a class or scoring schemes that award the respondent partial credit depending on pattern of options they select. Schmidt et. al. identify twenty-six different partial credit scoring schemes in the literature, varying in the range of possible scores, and the relative weighting of incorrectly selected (vs) incorrectly unselected options.

A particularly elegant approach to partial scoring is referred to as the $[-1/n, +1/n]$ approach (Schmidt. et. al 2021 #17). This approach is particularly appealing in the context of SGC3A, because it: (1) takes into account all information provided by the respondent: the pattern of what the select, and choose not to select; and (2) weights an unsure/blank/non-response as *superior* to an incorrect response.

In Partial Scoring $[-1/n, +1/n]$**:**
- Scores range from [-1, +1]
- One point is awarded if all options are *correct*
- One point point is subtracted if all options are *incorrect*.
- Intermediate results are credited as fractions accordingly ($+1/n$ for each correct, $-1/n$ for each incorrect)
- This results in *at chance performance* (i.e. half of the given options marked correctly), being awarded 0 points are awarded

This scoring is more consistent with the motivating theory that Triangular Graph readers start out with an incorrect (i.e. orthongal, cartesian) interpretation of the coordinate system, and transition to a correct (i.e. triangular) interpretation. But the first step in making this transition is realizing the cartesian interpration *is incorrect*, which may yield blank responses where the respondent is essentially saying, 'there is no correct answer to this question'.
Schmidt. et. al (2021) describe the *Partial*$_{[-1/n,+1/n]}$ scoring scheme as the *only* scoring method (of the 27 described) where respondents' scoring results can be interpreted as a percentage of their true knowledge. One important drawback of this method is that a respondent may receive credit (a great deal of credit, depending on the number of answer options n) even if she did not select *any* options. In the case (such as ours) where n is much greater than p (there are many more answer options than there are options meant to be selected), the previous partial scoring algorithm poses a challenge because the respondent can achieve an almost completely perfect score by selecting a small number of incorrect options.

The algorithm for **partial scoring** $[-1/n, +1/n]$ is given by:

$$f = (1/n * i) - (1/n * (n - i)) = (2i - n)/n$$

```
f_partialN <- function(i, n) {

  # print(paste("i is :",i," n is:",n))

  #if(n==0) return error
  ifelse((n==0),print("ERROR: n should not be 0"),"")

  #if(i >n ) return error
  ifelse((i > n),print("ERROR: i CANNOT BE GREATER THAN n"),"")
```

```
  return ((2*i - n) / n)
}
```

Scoring Algorithms and Properties

We can examine each scoring scheme with respect to certain statistical properties.

The **Expected Chance Score** of Multiple True-False (MTF) questions is calculated by the sum of the product of the binomial ($p = 0.5$) probabilities of each statement marked *correctly* with the corresponding score for that number of correctly marked statements. (Schmidt et. al. 2021, Albanese & Sabers (1988)). Importantly, i is *not* the number of selected *options*, but rather the number of *correctly indicated* items, where [T = correctly selected || correctly not selected] and [F = incorrectly selected || incorrectly not selected]_. The f_i refers to the

$$f_{chance} = \sum_{i=0}^{n} \binom{n}{i} * (0.5)^i * (1-0.5)^{n-i} * f_i = \sum_{i=0}^{n} \binom{n}{i} * (0.5)^n * f_i$$

where $n =$ number of options in MTF question (data points that can be selected)
$i =$ number of options marked correctly
$f_i =$ score for i options marked correctly

```
f_chance <- function(n, scheme) {

  if (n < 0) {"ERROR: n must be greater than 0"}
  if (!scheme %in% c("d","p")) {"ERROR: unknown scoring scheme"}
  else {
    #sum from i=0 to i=n
    s = 0; #starting value
    for (x in 0:n) {

      #binomial coefficient n choose x
      binom = choose(n,x)

      #binomial probability of n statements marked correctly
      bprob = 0.5^n

      #score for x correctly marked items
      if (scheme == "d"){
        f = f_dichom(x,n)
      } else if (scheme == "p") {
        f = f_partialN(x,n)
      }

      chance_at_x = (binom * bprob*f)
      s = s + chance_at_x
    }
  }
  s
}
```

Table 2: Properties of each scoring scheme for question with $n = 4$ response options

Scoring Scheme	score for $i of 4 correctly marked options					Expected Score at Chance
	f_0	f_1	f_2	f_3	f_4	
Dichotomous	0	0	0	0	1	0.0625
Partial$_{[-1/n, +1/n]}$	-1	-0.5	0	0.5	1	0

Note: $n=4$ response options yields $2^n = 2^4 =$ 16 possible responses

Comparison of Scoring Schemes

```
title <- "Properties of each scoring scheme for question with $n=4$ response options"
schemes <- c("Dichotomous", " Partial$_{[-1/n, +1/n]}$")
f_0 <- c(f_dichom(0,4), f_partialN(0,4))
f_1 <- c(f_dichom(1,4), f_partialN(1,4))
f_2 <- c(f_dichom(2,4), f_partialN(2,4))
f_3 <- c(f_dichom(3,4), f_partialN(3,4))
f_4 <- c(f_dichom(4,4), f_partialN(4,4))
ecs <- c(f_chance(4,"d"),f_chance(4,"p"))

names = c("Scoring Scheme",
              "$f_0$",
              "$f_1$",
              "$f_2$",
              "$f_3$",
              "$f_4$",
              "Expected Score at Chance")

dt <- cbind(schemes,f_0,f_1,f_2,f_3,f_4,ecs)

kbl(dt, col.names = names, caption = title)%>%
  kable_classic() %>%
  add_header_above(c(" " = 1, "score for $i$ of 4 correctly marked options" = 5, " "=1)) %>%
  footnote(general = paste("$n=4$ response options yields $2^n = 2^4 =$",2^4,"possible responses"),
           general_title = "Note: ",footnote_as_chunk = T)
```

```
#cleanup
rm(f_0, f_1, f_2, f_3, f_4, ecs, dt, names, schemes, title)
```

```
title <- "Properties of each scoring scheme for question with $n=15$ response options (SGC3A Q1 - Q5)"
schemes <- c("Dichotomous", " Partial$_{[-1/n, +1/n]}$")
f_0 <- c(f_dichom(0,15), round(f_partialN(0,15),2))
f_1 <- c(f_dichom(1,15), round(f_partialN(1,15),2))
f_2 <- c(f_dichom(2,15), round(f_partialN(2,15),2))
f_3 <- c(f_dichom(3,15), round(f_partialN(3,15),2))
f_4 <- c(f_dichom(4,15), round(f_partialN(4,15),2))
f_e <- c("...","...")
f_15 <- c(f_dichom(15,15), round(f_partialN(15,15),2))
ecs <- c(f_chance(15,"d"),f_chance(15,"p"))

names = c("Scoring Scheme",
```

Table 3: Properties of each scoring scheme for question with $n = 15$ response options (SGC3A Q1 - Q5)

Scoring Scheme	score for i of 15 correctly marked options							Expected Score at Cha
	f_0	f_1	f_2	f_3	f_4	$...$	f_{15}	
Dichotomous	0	0	0	0	0	...	1	0.000030517578125
Partial$_{[-1/n, +1/n]}$	-1	-0.87	-0.73	-0.6	-0.47	...	1	0

Note: $n=15$ response options yields $2^n = 2^{15} =$ 32768 possible responses

```
              "$f_0$",
              "$f_1$",
              "$f_2$",
              "$f_3$",
              "$f_4$",
              "$...$",
              "$f_{15}$",
              "Expected Score at Chance")

dt <- cbind(schemes,f_0,f_1,f_2,f_3,f_4,f_e,f_15,ecs)

kbl(dt, col.names = names, caption = title)%>%
  kable_classic() %>%
  add_header_above(c(" " = 1, "score for $i$ of 15 correctly marked options" = 7, " "=1)) %>%
  footnote(general = paste("$n=15$ response options yields $2^n = 2^{15} =$",2^(15),"possible responses
           general_title = "Note: ",footnote_as_chunk = T)
```

```
#cleanup
rm(f_0, f_1, f_2, f_3, f_4, f_e, f_15, ecs, names, schemes, title)
```

```
title <- "Properties of each scoring scheme for question with $n=18$ response options (SGC3A Q6 - Q15)"
schemes <- c("Dichotomous", " Partial$_{[-1/n, +1/n]}$")
f_0 <- c(f_dichom(0,18), round(f_partialN(0,18),2))
f_1 <- c(f_dichom(1,18), round(f_partialN(1,18),2))
f_2 <- c(f_dichom(2,18), round(f_partialN(2,18),2))
f_3 <- c(f_dichom(3,18), round(f_partialN(3,18),2))
f_4 <- c(f_dichom(4,18), round(f_partialN(4,18),2))
f_e <- c("...","...")
f_18 <- c(f_dichom(18,18), round(f_partialN(18,18),2))
ecs <- c(f_chance(18,"d"),f_chance(18,"p"))

names = c("Scoring Scheme",
              "$f_0$",
              "$f_1$",
              "$f_2$",
              "$f_3$",
              "$f_4$",
              "$...$",
              "$f_{18}$",
              "Expected Score at Chance")

dt <- cbind(schemes,f_0,f_1,f_2,f_3,f_4,f_e,f_18,ecs)
```

Table 4: Properties of each scoring scheme for question with $n = 18$ response options (SGC3A Q6 - Q15)

	score for i of 18 correctly marked options							
Scoring Scheme	f_0	f_1	f_2	f_3	f_4	$...$	f_{18}	Expected Score at Cha
Dichotomous	0	0	0	0	0	...	1	3.814697265625e-06
Partial$_{[-1/n, +1/n]}$	-1	-0.89	-0.78	-0.67	-0.56	...	1	0

Note: $n=18$ response options yields $2^n = 2^{18} =$ 262144 possible responses

```
kbl(dt, col.names = names, caption = title)%>%
  kable_classic() %>%
  add_header_above(c(" " = 1, "score for $i$ of 18 correctly marked options" = 7, " "=1)) %>%
  footnote(general = paste("$n=18$ response options yields $2^n = 2^{18} =$",2^(18),"possible responses
           general_title = "Note: ",footnote_as_chunk = T)
```

```
#cleanup
rm(f_0, f_1, f_2, f_3, f_4, f_e, f_18, ecs, names, schemes, title)
```

RESCORING

In SGC_3A we are fundamentally interested in understanding how a participant interprets the presented graph (stimulus). The *graph comprehension task* asks them to select the data points in the graph that meet the criteria posed in the question. This is known as a *first order graph reading* (i.e. extracting values from a graph).

To assess a particpant's performance, for each question (q=15) we will calculate the following scores:

An overall, strict score:
1. **Absolute Score** : using dichotomous scoring referencing true (Triangular) answer. (see 1.2)

Subscores, for each observed graph interpretation
2. **Triangular Score** : using partial scoring [+1/n,-1/n] referencing true (Triangular) answer.
3. **Orthongal Score** : using partial scoring [+1/n,-1/n] referencing (incorrect Orthogonal) answer.

Encode MAMC Responses as MTF

To calculate partial scores, first we need re-encode participant responses which are currently captured in the `answer` column of the `df_items` dataframe. In the present encoding, the letter corresponding to each response item (corresponding to a data point in the stimulus graph) the subject selected on the task interface, is concatenated and stored in `answer`.

For example, if the respondent selected data points A and B, `answer = AB`. We need to transform this into a single column for each possible response option, encoding whether or not the option was selected `A = 1, B = 1, C = 0 ...`

```r
#SPLIT DF_ITEMS
#into sub dfs to allow a 1-1 mapping with appropriate answer key

#scaffold phase control condition
item_responses_scaffold_111 <- df_items %>%
  #filter only q < 6, the 'scaffold' items
  filter(q < 6) %>%
  #filter only the control condition
  filter(condition == "111")

#scaffold phase impasse condition
item_responses_scaffold_121 <- df_items %>%
  #filter only q < 6, the 'scaffold' items
  filter(q < 6) %>%
  #filter only the control condition
  filter(condition == "121")

#test phase descriminant
item_responses_test <- df_items %>%
  #filter only q < 6, the 'scaffold' items
  filter(q > 5 )
  #note we don't need to filter condition bc qs and data are same across conditions

#SPREAD MCMA RESPONSE TO MTF COLUMNS
#encode the response column [response] as a series of T/F statements per data point

#scaffold phase CONTROL condition
item_responses_scaffold_111 <- item_responses_scaffold_111 %>%
  #split response to TF columns
  mutate(
    r_A = as.integer(str_detect(response,"A")), #is there a A?
    r_X = as.integer(str_detect(response,"X")), #is there a X?
    r_C = as.integer(str_detect(response,"C")), #is there a C?
    r_O = as.integer(str_detect(response,"O")), #is there a O?
    r_I = as.integer(str_detect(response,"I")), #is there a I?
    r_J = as.integer(str_detect(response,"J")), #is there a J?
    r_H = as.integer(str_detect(response,"H")), #is there a H?
    r_F = as.integer(str_detect(response,"F")), #is there a F?
    r_K = as.integer(str_detect(response,"K")), #is there a K?
    r_D = as.integer(str_detect(response,"D")), #is there a D?
    r_U = as.integer(str_detect(response,"U")), #is there a U?
    r_E = as.integer(str_detect(response,"E")), #is there a E?
    r_G = as.integer(str_detect(response,"G")), #is there a G?
    r_B = as.integer(str_detect(response,"B")), #is there a B?
    r_Z = as.integer(str_detect(response,"Z"))  #is there a Z?
)

#scaffold phase IMPASSE condition
item_responses_scaffold_121 <- item_responses_scaffold_121 %>%
  #split response to TF columns
  mutate(
    r_A = as.integer(str_detect(response,"A")), #is there a A?
    r_X = as.integer(str_detect(response,"X")), #is there a X?
```

```
    r_C = as.integer(str_detect(response,"C")), #is there a C?
    r_O = as.integer(str_detect(response,"O")), #is there a O?
    r_I = as.integer(str_detect(response,"I")), #is there a I?
    r_J = as.integer(str_detect(response,"J")), #is there a J?
    r_H = as.integer(str_detect(response,"H")), #is there a H?
    r_F = as.integer(str_detect(response,"F")), #is there a F?
    r_K = as.integer(str_detect(response,"K")), #is there a K?
    r_D = as.integer(str_detect(response,"D")), #is there a D?
    r_U = as.integer(str_detect(response,"U")), #is there a U?
    r_E = as.integer(str_detect(response,"E")), #is there a E?
    r_G = as.integer(str_detect(response,"G")), #is there a G?
    r_B = as.integer(str_detect(response,"B")), #is there a B?
    r_Z = as.integer(str_detect(response,"Z"))  #is there a Z?
)

#test phase
item_responses_test <- item_responses_test %>%
  #split response to TF columns
  mutate(
    r_A = as.integer(str_detect(response,"A")), #is there a A?
    r_B = as.integer(str_detect(response,"B")), #is there a B?
    r_C = as.integer(str_detect(response,"C")), #is there a C?
    r_D = as.integer(str_detect(response,"D")), #is there a D?
    r_E = as.integer(str_detect(response,"E")), #is there a E?
    r_F = as.integer(str_detect(response,"F")), #is there a F?
    r_G = as.integer(str_detect(response,"G")), #is there a G?
    r_H = as.integer(str_detect(response,"H")), #is there a H?
    r_I = as.integer(str_detect(response,"I")), #is there a I?
    r_J = as.integer(str_detect(response,"J")), #is there a J?
    r_K = as.integer(str_detect(response,"K")), #is there a K?
    r_L = as.integer(str_detect(response,"L")), #is there a L?
    r_M = as.integer(str_detect(response,"M")), #is there a M?
    r_N = as.integer(str_detect(response,"N")), #is there a N?
    r_O = as.integer(str_detect(response,"O")), #is there a O?
    r_P = as.integer(str_detect(response,"P")), #is there a P?
    r_Z = as.integer(str_detect(response,"Z")), #is there a Z?
    r_X = as.integer(str_detect(response,"X"))  #is there a X?
)


#VALIDATE SPLIT
#n rows in df_items should match sum of nrows in the sub dfs
nrow(df_items) == sum(nrow(item_responses_scaffold_111), nrow(item_responses_scaffold_121),
                      nrow(item_responses_test))
```

```
## [1] TRUE
```

Now we have three dataframes (one for each group of questions: scaffold phase, test phase, nondiscriminant) with subjects' response encoded as a series of T/F [1,0] states across all response options (represented as colums prefaced with `r_`)

Encode MAMC Answer Keys as MTF

Next, we read the answer keys for the question sets. Note that there is an answer key unique to each experimental condition, because the experimental manipulation (impasse vs. control) is established by changing the pattern of the underlying dataset, which in turn yields different 'correct' answers. The divergence in answers across conditions only holds for the first five questions (the scaffold manipulation), while the following 10 questions are displayed with the same dataset (and thus have the same answers, regardless of condition).

```
key_111 <- read_csv('static/keys/SGC3A_111_key.csv')
key_121 <- read_csv('static/keys/SGC3A_121_key.csv')
```

Next, we split the answer key encoding into MTF encoding, just as we did for the response data. Each column indicates whether that response option *should be selected* in order to count as a correct response. Columns prefixed with `tri_` represent triangularly-correct response key, and those prefixed with `orth_` represent orthongally-correct response key.

```
#SCAFFOLD KEY CONDITION 111
key_scaffolded_c111 <- key_111 %>%
  #filter only q < 6, the 'scaffold' items
  filter(Q<6) %>%
  #create "triangle correct" columns
  mutate(
    tri_A = as.integer(str_detect(TRIANGULAR,"A")), #is there a A in TRIANGULAR?
    tri_X = as.integer(str_detect(TRIANGULAR,"X")), #is there a X in TRIANGULAR?
    tri_C = as.integer(str_detect(TRIANGULAR,"C")), #is there a C in TRIANGULAR?
    tri_O = as.integer(str_detect(TRIANGULAR,"O")), #is there a O in TRIANGULAR?
    tri_I = as.integer(str_detect(TRIANGULAR,"I")), #is there a I in TRIANGULAR?
    tri_J = as.integer(str_detect(TRIANGULAR,"J")), #is there a J in TRIANGULAR?
    tri_H = as.integer(str_detect(TRIANGULAR,"H")), #is there a H in TRIANGULAR?
    tri_F = as.integer(str_detect(TRIANGULAR,"F")), #is there a F in TRIANGULAR?
    tri_K = as.integer(str_detect(TRIANGULAR,"K")), #is there a K in TRIANGULAR?
    tri_D = as.integer(str_detect(TRIANGULAR,"D")), #is there a D in TRIANGULAR?
    tri_U = as.integer(str_detect(TRIANGULAR,"U")), #is there a U in TRIANGULAR?
    tri_E = as.integer(str_detect(TRIANGULAR,"E")), #is there a E in TRIANGULAR?
    tri_G = as.integer(str_detect(TRIANGULAR,"G")), #is there a G in TRIANGULAR?
    tri_B = as.integer(str_detect(TRIANGULAR,"B")), #is there a B in TRIANGULAR?
    tri_Z = as.integer(str_detect(TRIANGULAR,"Z"))  #is there a Z in TRIANGULAR?
   ) %>%
  #create "orthogonal correct" columns
  mutate(
    orth_A = as.integer(str_detect(ORTHOGONAL,"A")), #is there a A in ORTHOGONAL?
    orth_X = as.integer(str_detect(ORTHOGONAL,"X")), #is there a X in ORTHOGONAL?
    orth_C = as.integer(str_detect(ORTHOGONAL,"C")), #is there a C in ORTHOGONAL?
    orth_O = as.integer(str_detect(ORTHOGONAL,"O")), #is there a O in ORTHOGONAL?
    orth_I = as.integer(str_detect(ORTHOGONAL,"I")), #is there a I in ORTHOGONAL?
    orth_J = as.integer(str_detect(ORTHOGONAL,"J")), #is there a J in ORTHOGONAL?
    orth_H = as.integer(str_detect(ORTHOGONAL,"H")), #is there a H in ORTHOGONAL?
    orth_F = as.integer(str_detect(ORTHOGONAL,"F")), #is there a F in ORTHOGONAL?
    orth_K = as.integer(str_detect(ORTHOGONAL,"K")), #is there a K in ORTHOGONAL?
    orth_D = as.integer(str_detect(ORTHOGONAL,"D")), #is there a D in ORTHOGONAL?
    orth_U = as.integer(str_detect(ORTHOGONAL,"U")), #is there a U in ORTHOGONAL?
    orth_E = as.integer(str_detect(ORTHOGONAL,"E")), #is there a E in ORTHOGONAL?
```

```
    orth_G = as.integer(str_detect(ORTHOGONAL,"G")), #is there a G in ORTHOGONAL?
    orth_B = as.integer(str_detect(ORTHOGONAL,"B")), #is there a B in ORTHOGONAL?
    orth_Z = as.integer(str_detect(ORTHOGONAL,"Z"))  #is there a Z in ORTHOGONAL?
   )

#SCAFFOLD KEY CONDITION 121
key_scaffolded_c121 <- key_121 %>%
  #filter only q < 6, the 'scaffold' items
  filter(Q<6) %>%
  #create "triangle correct" columns
  mutate(
    tri_A = as.integer(str_detect(TRIANGULAR,"A")), #is there a A in TRIANGULAR?
    tri_X = as.integer(str_detect(TRIANGULAR,"X")), #is there a X in TRIANGULAR?
    tri_C = as.integer(str_detect(TRIANGULAR,"C")), #is there a C in TRIANGULAR?
    tri_O = as.integer(str_detect(TRIANGULAR,"O")), #is there a O in TRIANGULAR?
    tri_I = as.integer(str_detect(TRIANGULAR,"I")), #is there a I in TRIANGULAR?
    tri_J = as.integer(str_detect(TRIANGULAR,"J")), #is there a J in TRIANGULAR?
    tri_H = as.integer(str_detect(TRIANGULAR,"H")), #is there a H in TRIANGULAR?
    tri_F = as.integer(str_detect(TRIANGULAR,"F")), #is there a F in TRIANGULAR?
    tri_K = as.integer(str_detect(TRIANGULAR,"K")), #is there a K in TRIANGULAR?
    tri_D = as.integer(str_detect(TRIANGULAR,"D")), #is there a D in TRIANGULAR?
    tri_U = as.integer(str_detect(TRIANGULAR,"U")), #is there a U in TRIANGULAR?
    tri_E = as.integer(str_detect(TRIANGULAR,"E")), #is there a E in TRIANGULAR?
    tri_G = as.integer(str_detect(TRIANGULAR,"G")), #is there a G in TRIANGULAR?
    tri_B = as.integer(str_detect(TRIANGULAR,"B")), #is there a B in TRIANGULAR?
    tri_Z = as.integer(str_detect(TRIANGULAR,"Z"))  #is there a Z in TRIANGULAR?
   ) %>%
  #create "orthogonal correct" columns
  mutate(
    orth_A = as.integer(str_detect(ORTHOGONAL,"A")), #is there a A in ORTHOGONAL?
    orth_X = as.integer(str_detect(ORTHOGONAL,"X")), #is there a X in ORTHOGONAL?
    orth_C = as.integer(str_detect(ORTHOGONAL,"C")), #is there a C in ORTHOGONAL?
    orth_O = as.integer(str_detect(ORTHOGONAL,"O")), #is there a O in ORTHOGONAL?
    orth_I = as.integer(str_detect(ORTHOGONAL,"I")), #is there a I in ORTHOGONAL?
    orth_J = as.integer(str_detect(ORTHOGONAL,"J")), #is there a J in ORTHOGONAL?
    orth_H = as.integer(str_detect(ORTHOGONAL,"H")), #is there a H in ORTHOGONAL?
    orth_F = as.integer(str_detect(ORTHOGONAL,"F")), #is there a F in ORTHOGONAL?
    orth_K = as.integer(str_detect(ORTHOGONAL,"K")), #is there a K in ORTHOGONAL?
    orth_D = as.integer(str_detect(ORTHOGONAL,"D")), #is there a D in ORTHOGONAL?
    orth_U = as.integer(str_detect(ORTHOGONAL,"U")), #is there a U in ORTHOGONAL?
    orth_E = as.integer(str_detect(ORTHOGONAL,"E")), #is there a E in ORTHOGONAL?
    orth_G = as.integer(str_detect(ORTHOGONAL,"G")), #is there a G in ORTHOGONAL?
    orth_B = as.integer(str_detect(ORTHOGONAL,"B")), #is there a B in ORTHOGONAL?
    orth_Z = as.integer(str_detect(ORTHOGONAL,"Z"))  #is there a Z in ORTHOGONAL?
   )

#TEST KEY
#key_111 == key_121 across both conditions for q>5
key_test <- key_111 %>%
  #filter only q < 6, the 'scaffold' items
  filter(Q>5) %>%
  #create "triangle correct" columns
  mutate(
```

```
    tri_A = as.integer(str_detect(TRIANGULAR, "A")), #is there a A in TRIANGULAR?
    tri_B = as.integer(str_detect(TRIANGULAR, "B")), #is there a B in TRIANGULAR?
    tri_C = as.integer(str_detect(TRIANGULAR, "C")), #is there a C in TRIANGULAR?
    tri_D = as.integer(str_detect(TRIANGULAR, "D")), #is there a D in TRIANGULAR?
    tri_E = as.integer(str_detect(TRIANGULAR, "E")), #is there a E in TRIANGULAR?
    tri_F = as.integer(str_detect(TRIANGULAR, "F")), #is there a F in TRIANGULAR?
    tri_G = as.integer(str_detect(TRIANGULAR, "G")), #is there a G in TRIANGULAR?
    tri_H = as.integer(str_detect(TRIANGULAR, "H")), #is there a H in TRIANGULAR?
    tri_I = as.integer(str_detect(TRIANGULAR, "I")), #is there a I in TRIANGULAR?
    tri_J = as.integer(str_detect(TRIANGULAR, "J")), #is there a J in TRIANGULAR?
    tri_K = as.integer(str_detect(TRIANGULAR, "K")), #is there a K in TRIANGULAR?
    tri_L = as.integer(str_detect(TRIANGULAR, "L")), #is there a L in TRIANGULAR?
    tri_M = as.integer(str_detect(TRIANGULAR, "M")), #is there a M in TRIANGULAR?
    tri_N = as.integer(str_detect(TRIANGULAR, "N")), #is there a N in TRIANGULAR?
    tri_O = as.integer(str_detect(TRIANGULAR, "O")), #is there a O in TRIANGULAR?
    tri_P = as.integer(str_detect(TRIANGULAR, "P")), #is there a P in TRIANGULAR?
    tri_Z = as.integer(str_detect(TRIANGULAR, "Z")), #is there a Z in TRIANGULAR?
    tri_X = as.integer(str_detect(TRIANGULAR, "X"))  #is there a X in TRIANGULAR?
  ) %>%
  #create "orthogonal correct" columns
  mutate(
    orth_A = as.integer(str_detect(ORTHOGONAL, "A")), #is there a A in ORTHOGONAL?
    orth_B = as.integer(str_detect(ORTHOGONAL, "B")), #is there a B in ORTHOGONAL?
    orth_C = as.integer(str_detect(ORTHOGONAL, "C")), #is there a C in ORTHOGONAL?
    orth_D = as.integer(str_detect(ORTHOGONAL, "D")), #is there a D in ORTHOGONAL?
    orth_E = as.integer(str_detect(ORTHOGONAL, "E")), #is there a E in ORTHOGONAL?
    orth_F = as.integer(str_detect(ORTHOGONAL, "F")), #is there a F in ORTHOGONAL?
    orth_G = as.integer(str_detect(ORTHOGONAL, "G")), #is there a G in ORTHOGONAL?
    orth_H = as.integer(str_detect(ORTHOGONAL, "H")), #is there a H in ORTHOGONAL?
    orth_I = as.integer(str_detect(ORTHOGONAL, "I")), #is there a I in ORTHOGONAL?
    orth_J = as.integer(str_detect(ORTHOGONAL, "J")), #is there a J in ORTHOGONAL?
    orth_K = as.integer(str_detect(ORTHOGONAL, "K")), #is there a K in ORTHOGONAL?
    orth_L = as.integer(str_detect(ORTHOGONAL, "L")), #is there a L in ORTHOGONAL?
    orth_M = as.integer(str_detect(ORTHOGONAL, "M")), #is there a M in ORTHOGONAL?
    orth_N = as.integer(str_detect(ORTHOGONAL, "N")), #is there a N in ORTHOGONAL?
    orth_O = as.integer(str_detect(ORTHOGONAL, "O")), #is there a O in ORTHOGONAL?
    orth_P = as.integer(str_detect(ORTHOGONAL, "P")), #is there a P in ORTHOGONAL?
    orth_Z = as.integer(str_detect(ORTHOGONAL, "Z")), #is there a Z in ORTHOGONAL?
    orth_X = as.integer(str_detect(ORTHOGONAL, "X"))  #is there a X in ORTHOGONAL?
  )
```

For sanity check, we veryify that the answer key for test phase questions (q > 5) is the *same* across the two condition specific answer keys. As long as this is TRUE, its OK to use `key_111`.

```
#verify that key_111 == key 121 for q>5
key_111 %>% filter(Q >5) %>% select(TRIANGULAR, ORTHOGONAL)== key_121 %>% filter(Q >5)%>% select(TRIANGU
```

```
##       TRIANGULAR ORTHOGONAL
##  [1,]       TRUE       TRUE
##  [2,]       TRUE       TRUE
##  [3,]       TRUE       TRUE
##  [4,]       TRUE       TRUE
##  [5,]       TRUE       TRUE
```

```
##  [6,]       TRUE       TRUE
##  [7,]       TRUE       TRUE
##  [8,]       TRUE       TRUE
##  [9,]       TRUE       TRUE
## [10,]       TRUE       TRUE
```

Calculate i *number correctly selected options*

Next, we calculate the i, number of correctly indicated options, based on the answer key for each question.

```
#-----------------------------------------------------------------------
#calculate i: number of correctly indicated options
#responses <- vector of T/F responses
#key <- vector of T/F answers
#RETURNS SUM correctly indicated items
#NOTE: THIS IS SUPER BRITTLE
#relies on fact that columns were ordered the same across the dataframes!
#should refactor in less imperative mode (more R like!)
#-----------------------------------------------------------------------
calc_i <- function(responses,key){
  # print(responses)
  # print(key)
  assessment <- responses == key
  return(sum(assessment))
}

#-----------------------------------------------------------------------
#write_i: write i to response dataframe
#items <- dataframe of items
#key <- MTF answerkey for this dataframe
#RETURNS MUTATING items dataframe
#-----------------------------------------------------------------------
write_i <- function(items,keys){
  #for each row(item) in the items input dataframe
  for (x in 1:nrow(items)) {
    #get the question number
    q = items[x,"q"]
    #get the subjects response vector
    responses <- as_tibble(items[x,] %>% select(starts_with("r_")))
    #get key vectors for this question
    tri_key = as_tibble(keys %>% filter(Q==q) %>% select(starts_with("tri_")))
    orth_key = as_tibble(keys %>% filter(Q==q) %>% select(starts_with("orth_")))
    #write TRI and ORTH response keys to row
    items[x,"TRI"] <- keys %>% filter(Q==q) %>% select(TRIANGULAR)
    items[x,"ORTH"] <- keys %>% filter(Q==q) %>% select(ORTHOGONAL)
    #calculate number of triangular-correct-options
    items[x,"tri_i"] <- calc_i(responses,tri_key)
    #calculate number of orthogonal-correct-options
    items[x,"orth_i"] <- calc_i(responses,orth_key)
  }
  return(items) #return mutated items dataframe
}
```

```
#-----------------------------------------------------------------------
#count_match: count the number of matching characters in the two strings
#response <- response string
#key <- key string
#returns count of matches
#-----------------------------------------------------------------------
count_match <- function(response, key){
  count = 0
  response = unlist(str_split(response,""))
  key = unlist(str_split(key,""))
  count = sum(table(response[response %in% key]))
  return(count)
}
```

```
#WARNING :: TAKES SEVERAL MINUTES TO RUN

#WRITE I_s
#~5 mins on MBP
#~30 seconds on IMAC
item_responses_scaffold_111 <- write_i(item_responses_scaffold_111,key_scaffolded_c111)
item_responses_scaffold_121 <- write_i(item_responses_scaffold_121,key_scaffolded_c121)
item_responses_test <- write_i(item_responses_test,key_test)
```

Calculate Scores

Finally, we calculate the interpretation scores, absolute score, and discriminant score.

```
#set n = number of answer options
n_scaffold <- 15
n_test <- 18

#calculate scores for scaffold phase CONTROL condition
item_responses_scaffold_111 <- item_responses_scaffold_111  %>% mutate(
  s_ABS = f_dichom(tri_i, n_scaffold),
  s_TRI = f_partialN(tri_i, n_scaffold),
  s_ORTH = f_partialN(orth_i,n_scaffold),
   #number of options in key
  t = str_length(TRI),
  r = str_length(ORTH),
  d = n_scaffold - (t+r),
  #number of selected options matching key
  t_s = Vectorize(count_match)(response,TRI),
  r_s = Vectorize(count_match)(response,ORTH),
  # d_s = , #todo add selections for other strategies
  # s = t_s + r_s + d_s
)

#calculate scores for scaffold phase IMPASSE condition
item_responses_scaffold_121 <- item_responses_scaffold_121  %>% mutate(
  s_ABS = f_dichom(tri_i, n_scaffold),
  s_TRI = f_partialN(tri_i, n_scaffold),
```

```
  s_ORTH = f_partialN(orth_i, n_scaffold),
   #number of options in key
  t = str_length(TRI),
  r = str_length(ORTH),
  d = n_scaffold - (t+r),
  #number of selected options matching key
  t_s = Vectorize(count_match)(response,TRI),
  r_s = Vectorize(count_match)(response,ORTH),
  # d_s = , #todo add selections for other strategies
  # s = t_s + r_s + d_s

)

#calculate scores for TEST phase (Q6 -> Q15)
item_responses_test <- item_responses_test  %>% mutate(
  s_ABS = f_dichom(tri_i, n_test),
  s_TRI = f_partialN(tri_i, n_test),
  s_ORTH = f_partialN(orth_i, n_test),
   #number of options in key
  t = str_length(TRI),
  r = str_length(ORTH),
  d = n_scaffold - (t+r),
  #number of selected options matching key
  t_s = Vectorize(count_match)(response,TRI),
  r_s = Vectorize(count_match)(response,ORTH),
  # d_s = , #todo add selections for other strategies
  # s = t_s + r_s + d_s

)
```

As a sanity check, we validate the equivalence of the scores

```
#validate that ABS score is always  == f_dichom(tri_i, 15)
unique(validate <- item_responses_scaffold_111$s_ABS == f_dichom(item_responses_scaffold_111$tri_i,n_sca
```

```
## [1] TRUE
```

```
unique(validate <- item_responses_scaffold_121$s_ABS == f_dichom(item_responses_scaffold_121$tri_i,n_sca
```

```
## [1] TRUE
```

```
unique(validate <- item_responses_test$s_ABS == f_dichom(item_responses_test$tri_i,n_test))
```

```
## [1] TRUE
```

```
#validate that ABS score is == 'correct' (calculated in stimulus)
unique(validate <- as.logical(item_responses_scaffold_111$s_ABS) == (item_responses_scaffold_111$correct
```

```
## [1] TRUE
```

```
unique(validate <- as.logical(item_responses_scaffold_121$s_ABS) == (item_responses_scaffold_121$correct
```

```
## [1] TRUE
```

```
unique(validate <- as.logical(item_responses_test$s_ABS) == (item_responses_test$correct))
```

```
## [1] TRUE
```

```
#validate that TRI score is always  == f_partialN(tri_i, 15)
unique(validate <- item_responses_scaffold_111$s_TRI == f_partialN(item_responses_scaffold_111$tri_i,n_s
```

```
## [1] TRUE
```

```
unique(validate <- item_responses_scaffold_121$s_TRI == f_partialN(item_responses_scaffold_121$tri_i,n_s
```

```
## [1] TRUE
```

```
unique(validate <- item_responses_test$s_TRI == f_partialN(item_responses_test$tri_i,n_test))
```

```
## [1] TRUE
```

```
#validate that ORTH score is always  == f_partialN(orth_i, 15)
unique(validate <- item_responses_scaffold_111$s_ORTH == f_partialN(item_responses_scaffold_111$orth_i,n
```

```
## [1] TRUE
```

```
unique(validate <- item_responses_scaffold_121$s_ORTH == f_partialN(item_responses_scaffold_121$orth_i,n
```

```
## [1] TRUE
```

```
unique(validate <- item_responses_test$s_ORTH == f_partialN(item_responses_test$orth_i,n_test))
```

```
## [1] TRUE
```

Reintegrate item dataframe

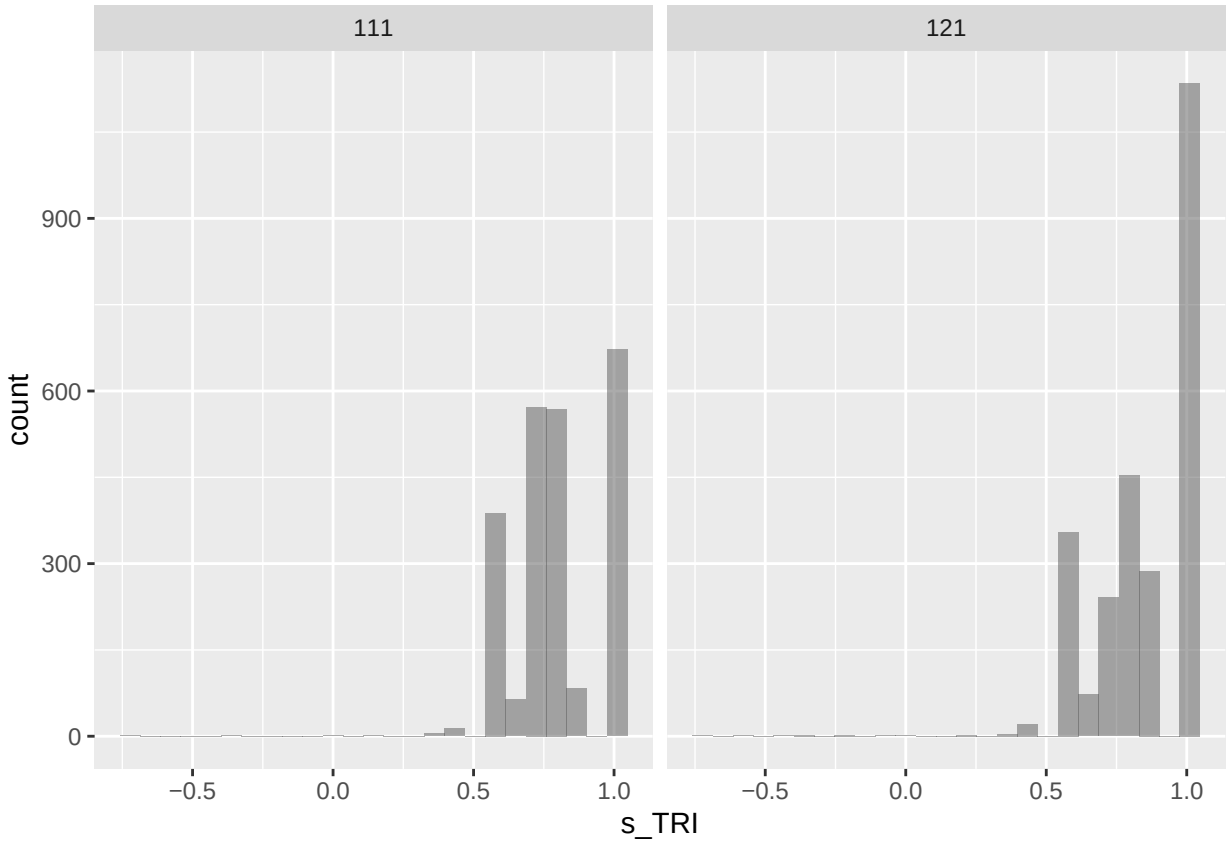
The final step in the process is to re_combine_ the item dataframes.

```
#reduce dataframes before combination
item_responses_scaffold_111 <- item_responses_scaffold_111 %>%
  select(subject, condition, term, mode, question, rt_s,
         q, correct, response, TRI, ORTH,
         num_o, tri_i, orth_i,
         s_ABS, s_TRI, s_ORTH) %>%
  mutate(phase = "LEARN")
```

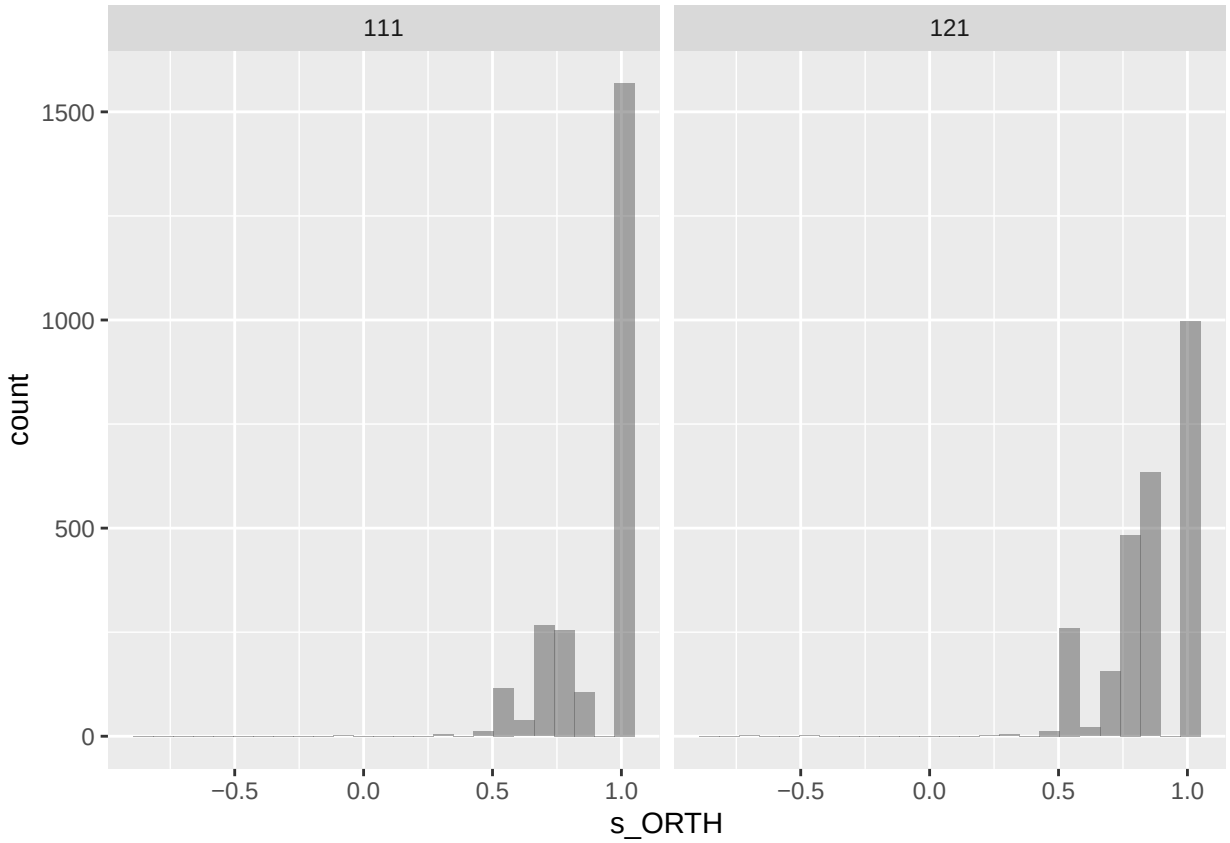
```
item_responses_scaffold_121 <- item_responses_scaffold_121 %>%
  select(subject, condition, term, mode, question, rt_s,
         q, correct, response, TRI, ORTH,
         num_o, tri_i, orth_i,
         s_ABS, s_TRI, s_ORTH) %>%
  mutate(phase = "LEARN")

item_responses_test <- item_responses_test %>%
  select(subject, condition, term, mode, question, rt_s,
         q, correct, response, TRI, ORTH,
         num_o, tri_i, orth_i,
         s_ABS, s_TRI, s_ORTH) %>%
  mutate(phase = "TEST")

#combine data frames
temp <- rbind(item_responses_scaffold_111,item_responses_scaffold_121,item_responses_test)

#dblck all items are accounted for
if ( nrow(df_items)==nrow(temp) ) {
  df_items <- temp
} else {
    print("ERROR! sub dfs don't contain all the df_items")
  }


#CLEANUP MTF ENCODED ITEMS
rm(item_responses_scaffold_111, item_responses_scaffold_121, item_responses_test)
rm(key_111, key_121, key_scaffolded_c111, key_scaffolded_c121, key_test)
rm(temp)
```

EXPLORATION

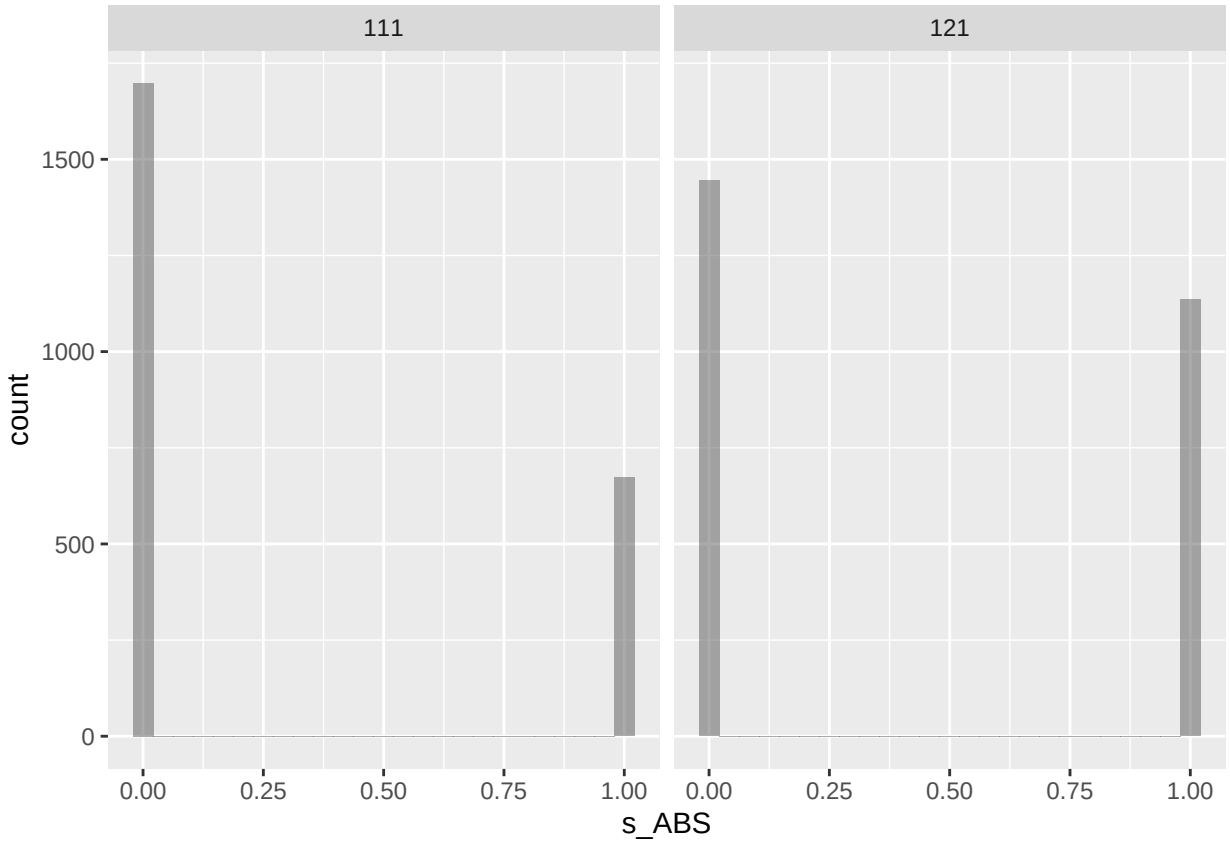
```
library(ggformula)

#only count discriminating items
df <- df_items %>% filter(!q %in% c(6,9) )

gf_histogram(~s_TRI, data = df_items) +
  facet_wrap(condition ~.)
```



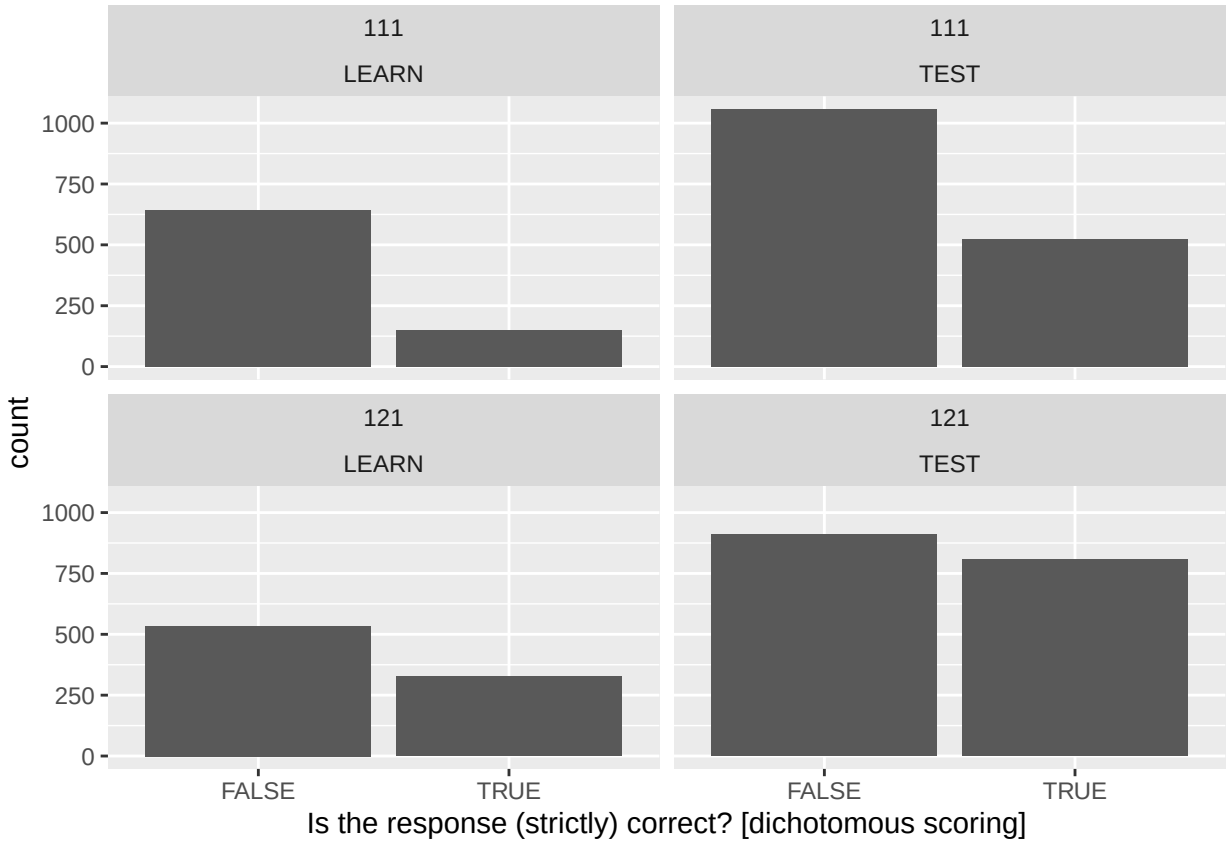

```
gf_histogram(~s_ORTH, data = df_items) +
  facet_wrap(condition ~.)
```




```
gf_histogram(~s_ABS, data = df_items) +
  facet_wrap(condition ~.)
```




```
gf_bar(~correct, data = df_items) +
  facet_wrap(condition ~ phase)
```



EXPORT

This is where we would summarize item-level scores and add them to the subjects-level dataset, and export item level and subject level files for further analysis.

RESOURCES

References

Schmidt, D., Raupach, T., Wiegand, A., Herrmann, M., & Kanzow, P. (2021). Relation between examinees' true knowledge and examination scores: Systematic review and exemplary calculations on Multiple-True-False items. Educational Research Review, 34, 100409. https://doi.org/10.1016/j.edurev.2021.100409

Albanese, M. A., & Sabers, D. L. (1988). Multiple True-False Items: A Study of Inter-item Correlations, Scoring Alternatives, and Reliability Estimation. Journal of Educational Measurement, 25(2), 111–123. https://doi.org/10.1111/j.1745-3984.1988.tb00296.x

Resources

on kable tables
https://cran.r-project.org/web/packages/kableExtra/vignettes/awesome_table_in_html.html

Session

```
sessionInfo()
```

```
## R version 4.0.2 (2020-06-22)
## Platform: x86_64-apple-darwin17.0 (64-bit)
## Running under: macOS  10.16
##
## Matrix products: default
## BLAS:   /Library/Frameworks/R.framework/Versions/4.0/Resources/lib/libRblas.dylib
## LAPACK: /Library/Frameworks/R.framework/Versions/4.0/Resources/lib/libRlapack.dylib
##
## locale:
## [1] en_US.UTF-8/en_US.UTF-8/en_US.UTF-8/C/en_US.UTF-8/en_US.UTF-8
##
## attached base packages:
## [1] stats     graphics  grDevices utils     datasets  methods   base
##
## other attached packages:
##  [1] ggformula_0.10.1 ggridges_0.5.3   scales_1.1.1     ggstance_0.3.5
##  [5] kableExtra_1.3.1 forcats_0.5.0    stringr_1.4.0    dplyr_1.0.2
##  [9] purrr_0.3.4      readr_1.4.0      tidyr_1.1.2      tibble_3.1.2
## [13] ggplot2_3.3.5    tidyverse_1.3.0
##
## loaded via a namespace (and not attached):
##  [1] Rcpp_1.0.5        lubridate_1.7.9   assertthat_0.2.1  digest_0.6.27
##  [5] utf8_1.2.1        ggforce_0.3.3     R6_2.5.0          cellranger_1.1.0
##  [9] plyr_1.8.6        backports_1.2.1   labelled_2.8.0    reprex_0.3.0
## [13] evaluate_0.14     highr_0.8         httr_1.4.2        pillar_1.6.1
## [17] rlang_0.4.11      readxl_1.3.1      rstudioapi_0.13   blob_1.2.1
## [21] rmarkdown_2.11    labeling_0.4.2    webshot_0.5.2     polyclip_1.10-0
## [25] munsell_0.5.0     broom_0.7.12      compiler_4.0.2    modelr_0.1.8
## [29] xfun_0.29         pkgconfig_2.0.3   htmltools_0.5.2   tidyselect_1.1.0
## [33] mosaicCore_0.9.0  fansi_0.5.0       viridisLite_0.4.0 crayon_1.4.1
## [37] dbplyr_1.4.4      withr_2.4.2       MASS_7.3-51.6     grid_4.0.2
## [41] jsonlite_1.7.1    gtable_0.3.0      lifecycle_1.0.0   DBI_1.1.0
## [45] magrittr_2.0.1    cli_3.3.0         stringi_1.7.3     farver_2.1.0
## [49] fs_1.5.0          xml2_1.3.2        ellipsis_0.3.2    generics_0.0.2
## [53] vctrs_0.3.8       tools_4.0.2       glue_1.6.2        tweenr_1.0.2
## [57] hms_0.5.3         fastmap_1.1.0     yaml_2.2.1        colorspace_2.0-2
## [61] rvest_0.3.6       knitr_1.37        haven_2.3.1
```