What determines the similarity of braille letters? A matrix of perceived letter similarity in braille by blind individuals

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Abstract

Letters are the essential components of words. In alphabetic writing systems, letter identification is generally understood as a hierarchical process: from the detection of letter features to the activation of the letter's abstract representation. Recent research has shown that this process is modulated by visual-letter similarity. To operationalize how visual similarity affects the interplay between printed input and abstract representations, researchers have created confusability matrices for letters in various alphabets. Here, we expand this research by examininig, in a parallel manner, the similarity of braille letters, as well as the features that make braille letters similar/dissimilar among themselves, for both naïve (sighted individuals) and expert braille readers (blind individuals). To do so, we conducted a same-different judgement task and created similarity matrices for accuracy and response times, and further analyzed the data via hierarchical clustering and linear mixed-effects models. This article presents a braille letter confusability matrix, and our findings evidencing the specific features, both perceptual and knowledge-based, that affect braille letter perception. These findings are important not only to design future studies on braille reading, but also to develop novel strategies for teaching the braille alphabet to both children and adults.

Keywords: Braille, Letter Identity Coding, Letter Confusability Matrix

Word count: X

What determines the similarity of braille letters? A matrix of perceived letter similarity in braille by blind individuals

Introduction

pga *Pablo's comments look like this*

abl *Ana's comments look like this*

mpl *Manolo's comments look like this*

jad *Jon Andoni's comments look like this*

pga *I propose the following organization for the paper: 1. Why is it important to know the features of characters in alphabetic systems" 2. Explain what Braille is 3. Say briefly what was done expirically and statistically*

We dont need the numberging below;It is moslty to keep track

pga *Why*

For most sighted people, the small raised dot patterns that configure braille characters feel like little more than an undifferentiated textured surface. Similarly, when we see graphemes of an alphabet or that we are unfamiliar with, it is hard to distinguish among the different symbols that, for the untrained eye, look "alike". However, expert readers (of braille, or any other writing system) automatically extract the critical features in letters, mostly unbothered by their accidental features. Indeed, there is a long tradition in the visual word recognition literature that has reliably demonstrated that the extraction of the relevant letter features to form abstract orthographic representations is quite robust to many manipulations (see Carreiras et al., 2012; Dehaene et al., 2005; Grainger et al., 2008; Pelli et al., 2006). On this general basis, many studies have been devoted to the examination of the similarity/confusability of letters in various alphabets (e.g., Roman: Simpson et al., 2013; see also Mueller & Weidemann, 2012 for a review; Arabic: Boudelaa et al., 2020; Wiley et al., 2016), which has allowed researchers to carry out further investigations in reading and word recognition while controlling for letter similarity (abl *CITE: e.g., XXXX Marcet...*), and examine ways to abl *Say something about expertise effects -> WILEY. and that together –> move towards a comprehensive understanding of letter identification and reading*

In visual reading research, a consensus has emerged regarding the extraction of features from the retinal image; in other words, we do not simply use the pattern of pixels, but instead we use lines, angles, and curves as the building blocks for letter recognition. However, braille letter perception has been far less studied and, therefore, its theoretical accounts have been discussed and examined in a smaller extent. Here we aim to understand what the features of braille letters are, and whether such features change depending on braille literacy.

Braille is unique among writing systems for many reasons. Of course, the most obvious one is that it was developed to be used by blind people though the sense of touch. Hence, it was devised taking into account the specific characteristics of the sensory modality at play, reflecting a compromise between amount of information and the skin's acuity. Importantly, the braille system is also significantly different from other contemporary writing systems because it is a modern invention (published in 1829; Braille (1829)) that has remained essentially unchanged since Louis Braille engineered it. In contrast, visual writing systems currently in used have evolved through cultural contact and ergonomic constraints over thousands of years.

Braille is a system of embossed dots whose basic unit is *the cell*, an array of 2x3 dots in which the different variations of raised dots form the elements of the written language (e.g., z = ⠵, ! = ⠖). Hence, an important characteristic of the braille writing system is its simplicity. Indeed, as Millar (2003) said, "Braille characters are bound to be similar to each other since they all derive from the same (2×3) matrix" (p. 32). In addition, braille is highly standardized in the shape and size of the matrix with minor variations in the standards set by different regulatory bodies; hence, there are not *glyphs* in braille.

An explanation of how Luis Braille devised the system is in order. As can be seen in Figure 1, the first 10 characters in the latin alphabet (a-j) are written using the top two rows of dots ⠁ ⠃ ⠉ ⠙ ⠑ ⠋ ⠛ ⠓ ⠊ ⠚, the next ten letters (k-t) repeat the patterns of the previous ten, adding a dot in the 3rd position ⠅ ⠇ ⠍ ⠝ ⠕ ⠏ ⠟ ⠗ ⠎ ⠞, the next group of letters (u - z) also repeat the pattern but add a dot in the 6th position ⠥ ⠧ ⠭ ⠽ ⠵. The w, not being part of the French alphabet when Louis Braille created this writing system, was later assigned the character ⠺. pga *"Later developments have include braille characters that are specific to particular langauges, for example, in English there areletter combiations such as "th" ⠹ and "ch" ⠡, and in Spanish there are character for accepted letters like á ⠷ or ñ ⠻ "*.

abl *briefly what has been done regarding confusion matrices and letter perception*

abl *confusion matrices: loomis, craigh*

abl *letter perception: millar*

One of the initial hypotheses on braille letter perception suggested that braille letters were perceived holistically, by their "global shape" (e.g., abl *CITE: Nolan & Kederis, 1969*). Nonetheless, in a series of experiments, abl *CITE: Millar 1977 a, b, 1985, see also 2003...* showed that was not the case, since . . . abl *explain results: high accurafcy in same/different but not able to recall/drawing...*. Indeed, Millar suggested that braille lacks prominent features and that letter perception in braille initially depends on dot density ("texture"), and that once learning has taken place, then shape coding occurs (i.e., the dots within a character can be located by reference to each other -> spatial organization)

. . . abl *link to what we're doing – even though "braille letters are bound to be similar to each* *other"...are all of them equally similar?*

. . . **pga** *Also, are there primitives in braille such as "vertical line"*

It is unclear from the literature the extent to which braille letters are similar to each other. Here. . .

pga *Brief intro on what we are doing*

- choice of task (common in visual modality) -> speeded same-different judgments for letter pairs (this task allows for normal perception conditions, while limiting the influence of task irrelevant knowledge, such as vocabulary knowledge) -> speeded = apparatus
- confussion matrices to examine what determines letter similarity in braille -> as research in visual modality
- Expertise effects in letter perception
- Dots/position weights -> is any position more important? Given that we know how it was created. . . (dot 3, 6. . .)

abl *importance*

Theoretical and practical reasons . . .

abl *limitations on interpretation*

The comparison between groups of course is not perfect: braille readers have greater tactile sensitivity in addition to knowledge about braille letters, and sighted individuals might use strategies, such as to mentally visualize the pattern, that are influenced by their vision experience. . . nonetheless, it is still possible to gain knowledge on tactile letter processing in general as well as the way literacy affects it, which, in turn, will assist on the improvement of teaching (practical) and models of word recognition and reading (theoretical)...

Experiment 1: Similarity judgements by naïve braille readers

Method

Participants

86 undergraduate students at DePaul University, who did not know how to read braille, were recruited through the subject pool system. All of them gave informed consent before their participation and earned one course-credit for taking part in the study. With this sample size, we wanted to ensure each pair of different letters was observed a minimum of 15 times (considering pairs containing the same two different letters in the opposite order as being different pairs [e.g., ⠇ ⠋ different from ⠋ ⠇], and taking into account that some trials may be lost in data cleaning).

Apparatus

We devised a system to control the presentation timing of braille stimuli while maintaining the needed movement of the fingertips across the braille letters from left to right. This system consists in a refreshable braille display placed on a motorized platform that moves the display horizontally at a set speed and distance. Hence, with this system we slid the braille letters on the braille display against participants fingers, instead of having participants moving their fingers from left to right to perceive the letters (abl *see Appendix X for a a more detailed description and visualization of the apparatus*). In addition, we used 3D stickers to indicate the area where the braille letters would appear, serving as reference points (start & end).

abl *maybe add something like: even though this is not the most ecological way to read, participants' performance while using this "passive-haptic" method was similar to their performance using the active exploration of the patterns (MA Thesis)*.

Materials

The study used all possible 2-letter combinations (n = 676) pairs. Out of those pairs, 26 were formed by the same two letters (e.g., ⠋ ⠋), and 650 formed by two different letters (e.g., ⠋ ⠞). In order to have the same amount of trials per condition (i,e., *same* and *different*), we created five different lists of pairs, each of them with 130 *same pairs*, and 130 *different pairs*. Hence, each participant perceived 266 trials, 6 practice plus 260 target trials. The order of presentation of the target trials was randomized for each participant.

3 PARTICIPANTS (87-89) ONLY 210!

Procedure

The experiment took place individually in a quiet room. We placed the refreshable braille display + moving platform system in the pull-out keyboard tray of the desktop, to avoid participants seeing the braille characters, and the keyboard used to respond on the desktop. Participants were instructed to place their index fingertip on the start position (after the first 3D sticker), to let the braille display slide against it, and to classify the two letters perceived as being *the same* two letters or as being two *different* letters–the letters "m" or "n" on the keyboard, respectively, with the non-dominant hand.

The braille display moved for 5 cm at 38.9 mm/s (35.9 mm/rev x 65 rpm / 60). This speed was chosen considering previous studies on passive touch (see Vega-Bermudez et al., 1991), as well as our own experience testing it. After moving said distance, the display stopped until participants responded and reset its position during the one-second ITI. The experimental session took around 30 minutes to complete.

Data analysis

Participants whose accuracy was below 51%, and trials in which response times (RTs) were either fatser than 600ms (time to)

Participants who performed at chance level or below, and trials in which responses were either faster than 200 ms or slower than 15000 ms were excluded from the analysis. Table 1 shows the mean accuracy per group and condition.

Results

```
## [1] 14
```

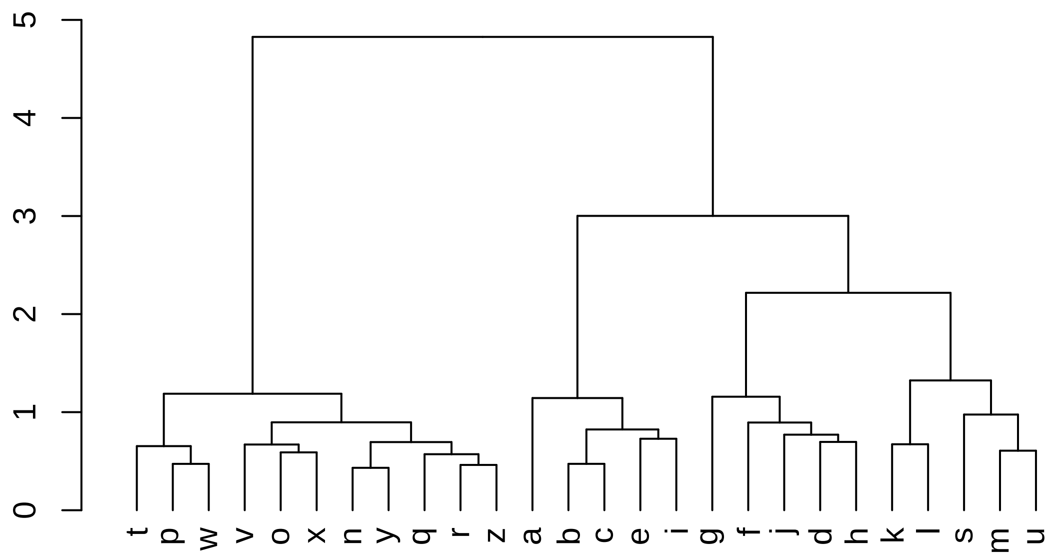
```
## Bayes factor analysis
## --------------
## [1] Alt., r=0.707 : 2955488 ±0%
##
## Against denominator:
##   Null, mu = 0
## ---
## Bayes factor type: BFoneSample, JZS
```

```
## Bayes factor analysis
## --------------
## [1] Alt., r=0.707 : 0.1300824 ±0%
##
## Against denominator:
##   Null, mu = 0
## ---
## Bayes factor type: BFoneSample, JZS
```

	a	b	c	d	e	f	g	h	i	j	k	l	
a	NA	0.979	0.948	0.992	0.992	0.930	0.944	0.906	0.915	0.954	1.008	0.946	0.
b	0.979	NA	0.993	1.026	0.988	0.990	0.990	0.969	1.047	1.074	0.942	0.982	0.
c	0.948	0.993	NA	0.980	1.060	0.955	1.011	1.074	1.020	1.119	0.991	0.938	0.
d	0.992	1.026	0.980	NA	1.077	1.038	1.014	1.063	1.092	0.980	1.052	1.184	1.
e	0.992	0.988	1.060	1.077	NA	1.004	0.974	1.028	1.010	1.160	0.923	1.052	0.
f	0.930	0.990	0.955	1.038	1.004	NA	1.014	1.045	1.145	1.107	1.051	0.995	0.
g	0.944	0.990	1.011	1.014	0.974	1.014	NA	1.139	0.950	1.020	0.887	1.004	1.
h	0.906	0.969	1.074	1.063	1.028	1.045	1.139	NA	1.070	1.070	0.994	1.010	1.
i	0.915	1.047	1.020	1.092	1.010	1.145	0.950	1.070	NA	1.002	0.946	0.970	1.
j	0.954	1.074	1.119	0.980	1.160	1.107	1.020	1.070	1.002	NA	1.142	1.054	0.
k	1.008	0.942	0.991	1.052	0.923	1.051	0.887	0.994	0.946	1.142	NA	1.080	1.
l	0.946	0.982	0.938	1.184	1.052	0.995	1.004	1.010	0.970	1.054	1.080	NA	0.
m	0.940	0.881	0.909	1.082	0.942	0.935	1.022	1.010	1.011	0.949	1.204	0.985	
n	0.935	0.908	1.010	0.968	1.040	1.027	0.935	0.978	0.943	1.054	0.991	0.925	0.
o	0.924	0.919	0.900	0.986	1.020	0.997	0.990	1.031	1.041	1.086	0.914	1.036	1.
p	0.863	0.970	0.977	0.920	0.934	0.965	1.059	0.931	0.973	1.015	0.934	1.003	1.
q	0.967	0.915	1.006	0.978	0.915	1.083	1.123	1.072	0.954	1.018	0.980	0.991	0.
r	0.922	0.953	0.931	0.883	0.943	1.079	0.994	1.054	0.963	1.067	0.938	0.977	1.
s	0.988	0.893	0.896	1.013	1.053	0.972	1.152	1.038	1.096	0.974	0.984	1.036	1.
t	0.936	0.978	0.931	1.065	0.954	0.961	1.059	0.995	0.958	1.068	0.917	0.939	1.
u	0.928	1.025	0.972	1.022	0.973	1.033	0.944	0.966	1.025	1.085	1.443	1.008	0.
v	0.921	0.981	0.936	0.974	0.966	1.010	1.214	1.136	0.944	0.983	1.044	1.220	0.
w	1.020	0.918	0.964	1.159	0.994	1.381	0.928	1.014	1.028	0.928	0.996	0.977	1.
x	0.980	0.911	0.903	0.966	0.961	0.993	1.006	0.951	0.962	1.041	0.926	1.067	1.
y	0.941	0.896	0.879	1.032	0.992	0.953	0.999	0.949	0.929	1.045	0.919	1.012	0.
z	0.903	0.907	0.918	0.859	0.945	0.918	0.952	1.042	0.999	1.008	0.953	0.968	0.

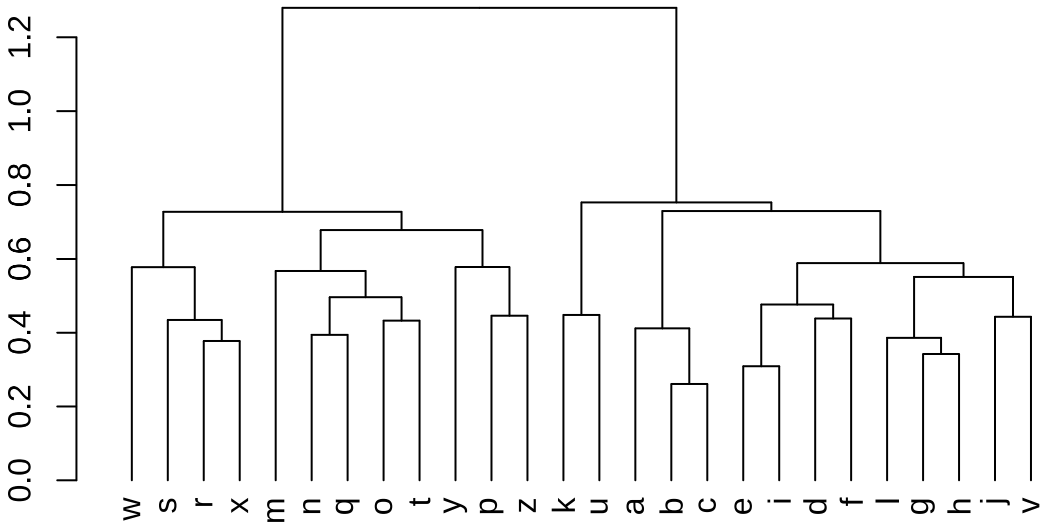
	a	b	c	d	e	f	g	h	i	j	k	l	
a	NA	1.021	1.054	1.008	1.008	1.075	1.059	1.104	1.092	1.048	0.992	1.057	1.
b	1.021	NA	1.007	0.975	1.013	1.010	1.010	1.032	0.955	0.931	1.062	1.018	1.
c	1.054	1.007	NA	1.020	0.943	1.048	0.989	0.932	0.980	0.893	1.009	1.067	1.
d	1.008	0.975	1.020	NA	0.929	0.964	0.986	0.941	0.915	1.020	0.950	0.845	0.
e	1.008	1.013	0.943	0.929	NA	0.996	1.027	0.972	0.990	0.862	1.083	0.951	1.
f	1.075	1.010	1.048	0.964	0.996	NA	0.986	0.957	0.873	0.903	0.951	1.005	1.
g	1.059	1.010	0.989	0.986	1.027	0.986	NA	0.878	1.053	0.981	1.127	0.996	0.
h	1.104	1.032	0.932	0.941	0.972	0.957	0.878	NA	0.934	0.934	1.007	0.990	0.
i	1.092	0.955	0.980	0.915	0.990	0.873	1.053	0.934	NA	0.998	1.057	1.030	0.
j	1.048	0.931	0.893	1.020	0.862	0.903	0.981	0.934	0.998	NA	0.876	0.949	1.
k	0.992	1.062	1.009	0.950	1.083	0.951	1.127	1.007	1.057	0.876	NA	0.925	0.
l	1.057	1.018	1.067	0.845	0.951	1.005	0.996	0.990	1.030	0.949	0.925	NA	1.
m	1.063	1.135	1.100	0.925	1.062	1.070	0.979	0.991	0.989	1.054	0.830	1.015	
n	1.069	1.101	0.990	1.033	0.961	0.974	1.070	1.022	1.060	0.949	1.009	1.081	1.
o	1.082	1.088	1.111	1.014	0.980	1.004	1.010	0.970	0.961	0.920	1.094	0.965	0.
p	1.158	1.030	1.024	1.087	1.071	1.036	0.944	1.074	1.028	0.985	1.070	0.997	0.
q	1.035	1.092	0.995	1.022	1.092	0.923	0.890	0.933	1.049	0.982	1.021	1.009	1.
r	1.084	1.049	1.074	1.132	1.060	0.926	1.007	0.949	1.039	0.937	1.067	1.023	0.
s	1.012	1.120	1.115	0.987	0.950	1.029	0.868	0.964	0.912	1.027	1.016	0.965	0.
t	1.068	1.022	1.074	0.939	1.048	1.041	0.944	1.005	1.044	0.936	1.090	1.066	0.
u	1.078	0.976	1.028	0.979	1.028	0.968	1.060	1.036	0.976	0.922	0.693	0.992	1.
v	1.086	1.019	1.068	1.026	1.036	0.991	0.823	0.881	1.060	1.017	0.957	0.819	1.
w	0.980	1.089	1.037	0.863	1.006	0.724	1.078	0.987	0.973	1.078	1.004	1.024	0.
x	1.020	1.097	1.107	1.035	1.041	1.007	0.994	1.052	1.040	0.961	1.080	0.937	0.
y	1.063	1.116	1.138	0.969	1.008	1.050	1.002	1.054	1.076	0.957	1.088	0.988	1.
z	1.108	1.102	1.089	1.163	1.058	1.089	1.050	0.960	1.001	0.992	1.050	1.033	1.

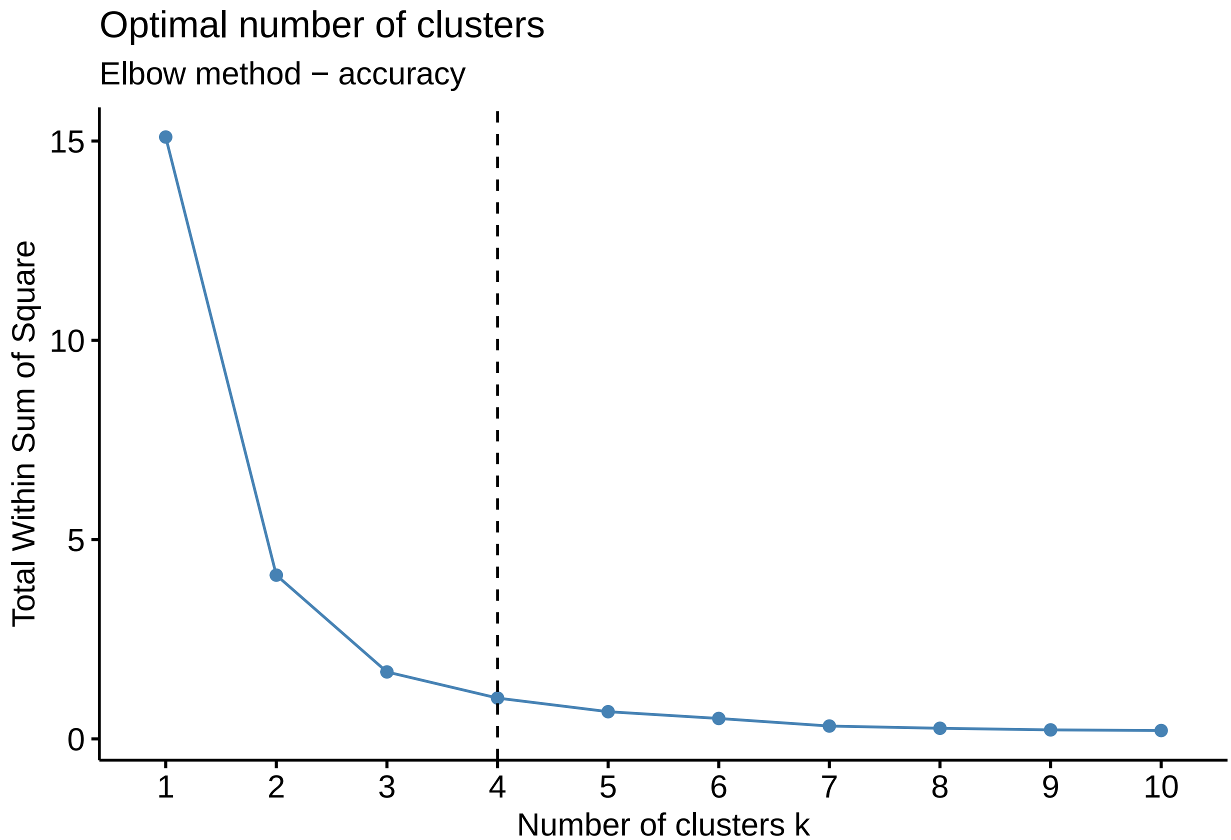
```
##   average    single  complete      ward
## 0.6270286 0.3390563 0.7372065 0.8636821
```

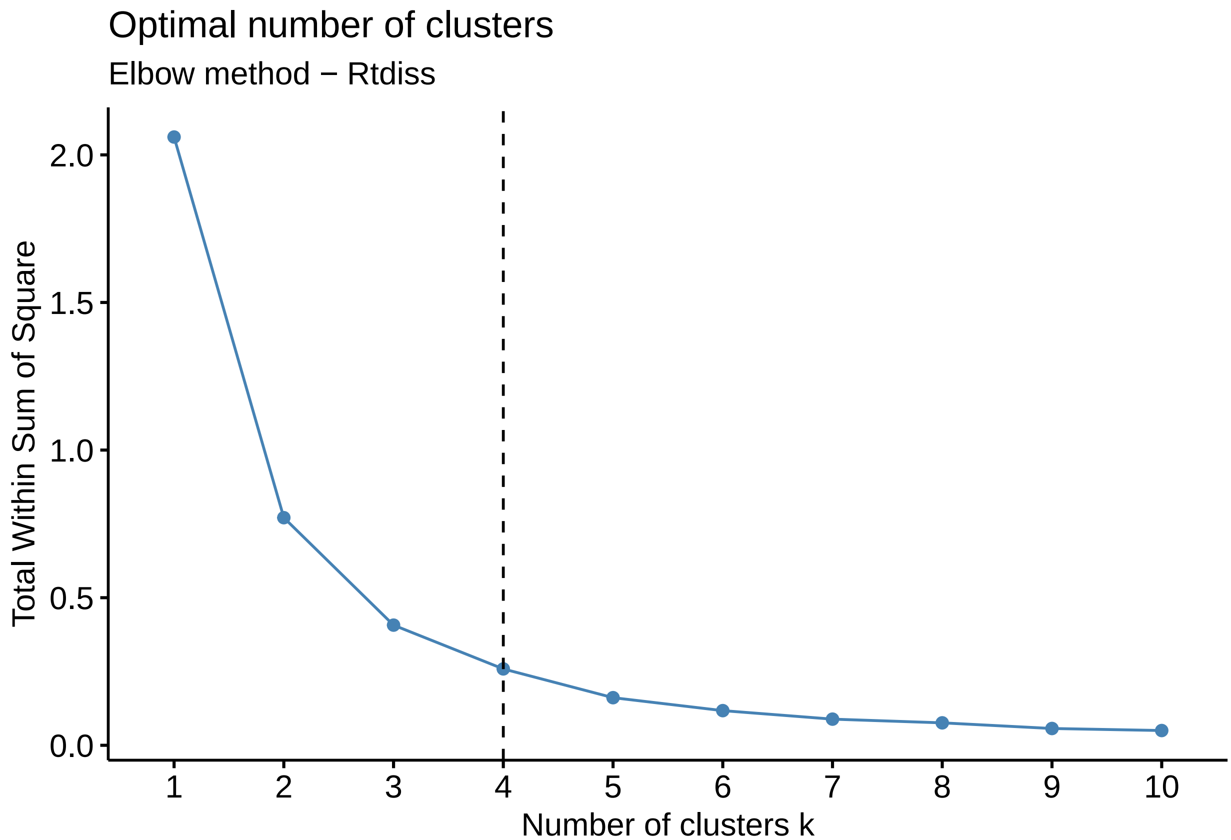



```
##  [1] 20 16 23 22 15 24 14 25 17 18 26  1  2  3  5  9  7  6 10  4  8 11 12 19 13
## [26] 21
```

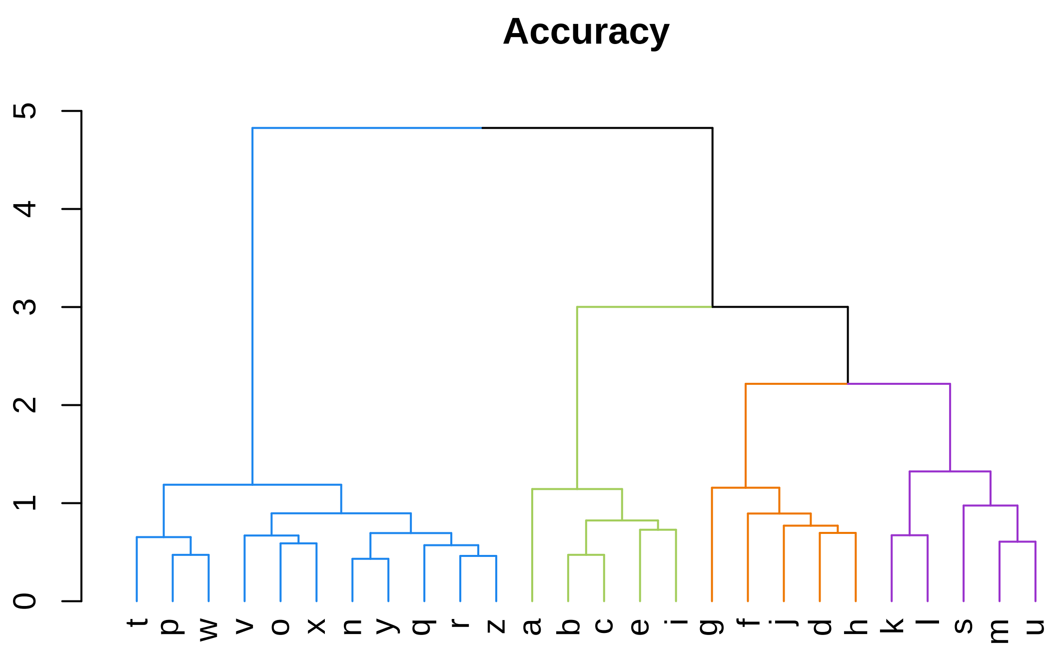
```
##   average    single  complete      ward
## 0.3185801 0.1944902 0.4879093 0.6774162
```


0.0
0.2
0.4
0.6
0.8
1.0
1.2
w s r x m n q o t y p z k u a b c e i d f l g h j v

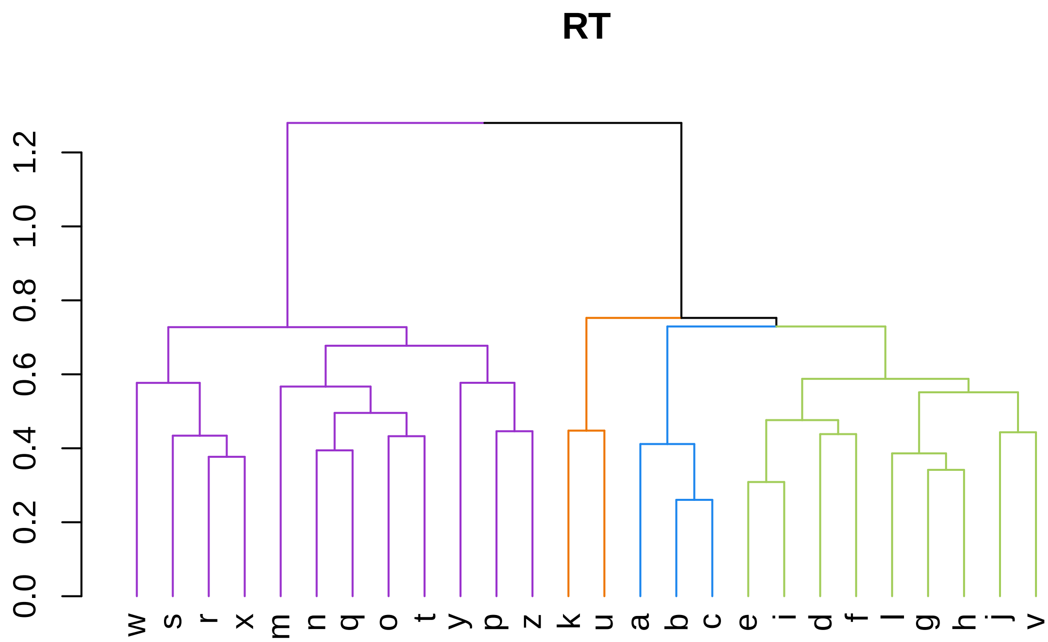

Optimal number of clusters
Elbow method − accuracy
Total Within Sum of Square
0
5
10
15
1
2
3
4
5
6
7
8
9
10
Number of clusters k


Optimal number of clusters
Elbow method − Rtdiss
Total Within Sum of Square
2.0
1.5
1.0
0.5
0.0
1
2
3
4
5
6
7
8
9
10
Number of clusters k

209



210



Discussion

Experiment 2: Ciegos

Motor Control

- file = "motor_control_BF-ino"
- speed = 7000rpm (left to right); 260 rpm (right to left –> because of Miguel)
- distance = 250 steps (~4.5cm)

REMEMBER. To calculate speed:

1. steps/mm = 200$1/2$20 = 5
2. mm/rev = 200/5 = 40 (IN VALENCIA - CHI different because different pulley)
3. mm/sec = 40*rpm/60

Method

Participants

24 blind adult individuals…

Material

All combinations. 5 lists (some 4… PANDEMIC)

Procedure

Data analysis

Results

```
##
##  Paired t-test
##
## data:  Acc.orders$MAcc1 and Acc.orders$MAcc2
## t = 0.67851, df = 324, p-value = 0.4979
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
##  -0.003492687  0.007170277
## sample estimates:
## mean of the differences
##             0.001838795
```

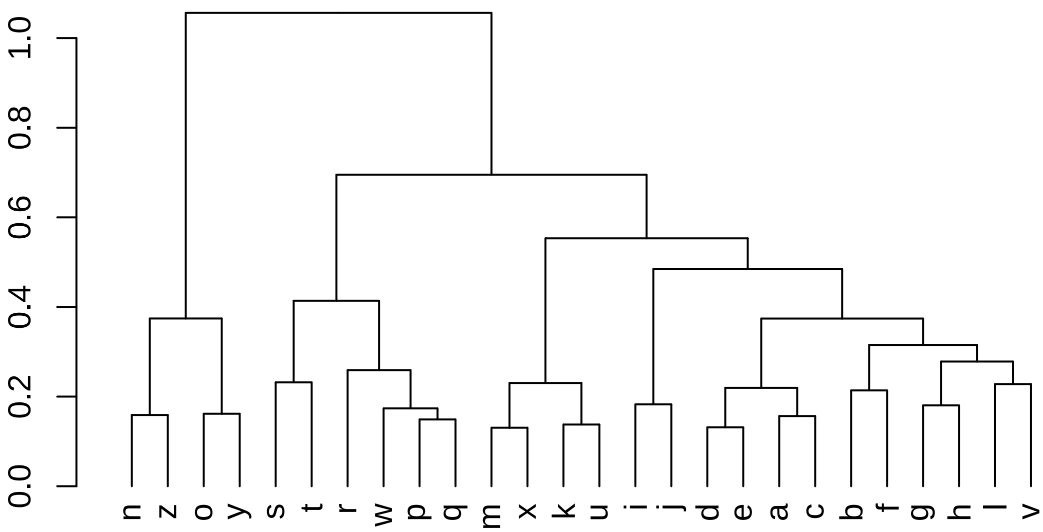
```
##
##  Paired t-test
##
## data:  RT.orders.blind$MNRT1 and RT.orders.blind$MNRT2
## t = -1.6644, df = 324, p-value = 0.09701
```

```
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
##  -0.01314649  0.00109665
## sample estimates:
## mean of the differences
##            -0.006024921
```

	a	b	c	d	e	f	g	h	i	j	k	l	
a	NA	0.948	1.099	0.970	0.954	1.045	0.996	0.962	1.037	0.956	1.000	1.016	0.
b	0.948	NA	1.022	1.006	0.992	1.022	1.005	1.020	1.002	1.004	0.950	1.045	0.
c	1.099	1.022	NA	1.028	0.946	0.960	0.957	0.965	0.966	0.986	0.977	0.960	0.
d	0.970	1.006	1.028	NA	1.129	1.100	0.990	1.018	0.986	1.047	1.035	1.003	0.
e	0.954	0.992	0.946	1.129	NA	0.988	1.139	1.011	1.056	0.994	0.963	0.944	0.
f	1.045	1.022	0.960	1.100	0.988	NA	1.085	1.064	0.995	1.086	1.006	1.008	0.
g	0.996	1.005	0.957	0.990	1.139	1.085	NA	1.061	0.974	1.011	0.926	1.012	0.
h	0.962	1.020	0.965	1.018	1.011	1.064	1.061	NA	0.999	1.130	0.946	0.992	0.
i	1.037	1.002	0.966	0.986	1.056	0.995	0.974	0.999	NA	1.107	1.008	0.946	0.
j	0.956	1.004	0.986	1.047	0.994	1.086	1.011	1.130	1.107	NA	0.936	0.976	0.
k	1.000	0.950	0.977	1.035	0.963	1.006	0.926	0.946	1.008	0.936	NA	0.980	1.
l	1.016	1.045	0.960	1.003	0.944	1.008	1.012	0.992	0.946	0.976	0.980	NA	1.
m	0.993	0.923	0.942	0.972	0.966	0.951	0.974	0.941	0.992	0.906	1.060	1.006	
n	0.964	1.001	0.959	0.967	0.948	0.997	0.966	0.999	0.954	1.010	1.039	0.950	0.
o	0.966	0.980	0.945	0.957	1.027	0.955	0.992	0.988	0.974	0.983	1.030	0.966	0.
p	0.946	0.996	0.954	0.958	0.931	0.943	1.044	0.990	1.006	0.918	1.002	1.056	0.
q	1.000	0.970	1.022	0.945	0.980	1.085	1.089	0.960	0.951	0.972	0.955	0.980	0.
r	0.943	1.000	0.985	0.985	0.996	1.007	1.030	1.010	0.984	0.993	1.010	1.064	0.
s	0.984	1.001	0.931	0.967	0.970	1.072	0.976	1.009	1.034	0.992	0.990	0.976	0.
t	1.010	0.988	0.967	0.998	0.962	0.969	0.994	0.982	0.980	0.978	0.960	0.996	0.
u	0.992	0.931	0.977	0.924	0.942	0.979	0.978	0.959	0.951	0.977	1.229	1.030	1.
v	0.952	0.955	0.975	0.972	0.933	0.954	0.962	0.997	0.944	0.983	0.978	1.015	0.
w	0.968	0.970	0.978	1.000	1.027	0.994	0.968	1.041	0.960	1.007	1.038	0.998	0.
x	0.945	0.970	0.945	0.994	0.968	0.967	0.973	0.990	0.972	0.958	1.000	0.996	1.
y	1.070	0.970	0.914	0.986	0.909	0.980	1.084	0.963	0.967	0.973	0.994	0.993	1.
z	0.948	0.976	0.962	0.964	0.979	0.980	0.990	1.004	0.999	0.968	0.990	0.980	0.

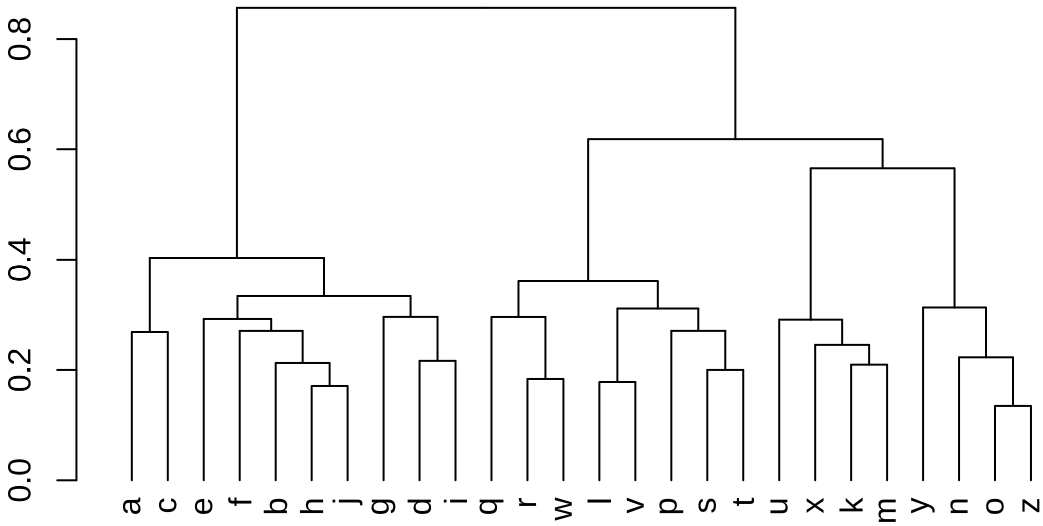
	a	b	c	d	e	f	g	h	i	j	k	l	
a	NA	1.055	0.910	1.031	1.049	0.957	1.004	1.040	0.964	1.047	1.000	0.984	1.
b	1.055	NA	0.978	0.994	1.008	0.979	0.995	0.980	0.998	0.997	1.053	0.957	1.
c	0.910	0.978	NA	0.972	1.057	1.041	1.045	1.036	1.035	1.015	1.024	1.042	1.
d	1.031	0.994	0.972	NA	0.886	0.909	1.010	0.982	1.015	0.955	0.966	0.997	1.
e	1.049	1.008	1.057	0.886	NA	1.012	0.878	0.989	0.947	1.006	1.038	1.059	1.
f	0.957	0.979	1.041	0.909	1.012	NA	0.922	0.939	1.005	0.921	0.994	0.992	1.
g	1.004	0.995	1.045	1.010	0.878	0.922	NA	0.943	1.027	0.989	1.080	0.988	1.
h	1.040	0.980	1.036	0.982	0.989	0.939	0.943	NA	1.001	0.885	1.058	1.008	1.
i	0.964	0.998	1.035	1.015	0.947	1.005	1.027	1.001	NA	0.903	0.992	1.058	1.
j	1.047	0.997	1.015	0.955	1.006	0.921	0.989	0.885	0.903	NA	1.068	1.025	1.
k	1.000	1.053	1.024	0.966	1.038	0.994	1.080	1.058	0.992	1.068	NA	1.020	0.
l	0.984	0.957	1.042	0.997	1.059	0.992	0.988	1.008	1.058	1.025	1.020	NA	0.
m	1.007	1.083	1.062	1.029	1.035	1.052	1.026	1.063	1.008	1.104	0.943	0.994	
n	1.038	1.000	1.043	1.034	1.055	1.003	1.035	1.001	1.049	0.991	0.962	1.053	1.
o	1.035	1.020	1.058	1.045	0.973	1.047	1.008	1.012	1.027	1.017	0.971	1.035	1.
p	1.057	1.004	1.049	1.044	1.074	1.061	0.958	1.011	0.994	1.089	0.999	0.947	1.
q	1.000	1.030	0.978	1.059	1.020	0.921	0.918	1.042	1.052	1.028	1.047	1.020	1.
r	1.061	1.000	1.015	1.015	1.004	0.993	0.971	0.991	1.016	1.007	0.990	0.940	1.
s	1.017	0.999	1.075	1.034	1.031	0.932	1.025	0.991	0.967	1.008	1.011	1.025	1.
t	0.991	1.012	1.034	1.002	1.040	1.032	1.006	1.018	1.020	1.023	1.042	1.004	1.
u	1.008	1.074	1.024	1.082	1.062	1.021	1.022	1.043	1.052	1.024	0.813	0.970	0.
v	1.050	1.047	1.026	1.029	1.072	1.048	1.039	1.003	1.059	1.017	1.022	0.985	1.
w	1.033	1.031	1.022	1.000	0.973	1.006	1.033	0.961	1.042	0.993	0.963	1.002	1.
x	1.058	1.031	1.059	1.006	1.033	1.034	1.028	1.011	1.029	1.044	1.000	1.004	0.
y	0.934	1.031	1.094	1.014	1.100	1.020	0.922	1.038	1.034	1.027	1.006	1.007	0.
z	1.055	1.025	1.040	1.037	1.021	1.020	1.010	0.997	1.001	1.033	1.011	1.020	1.

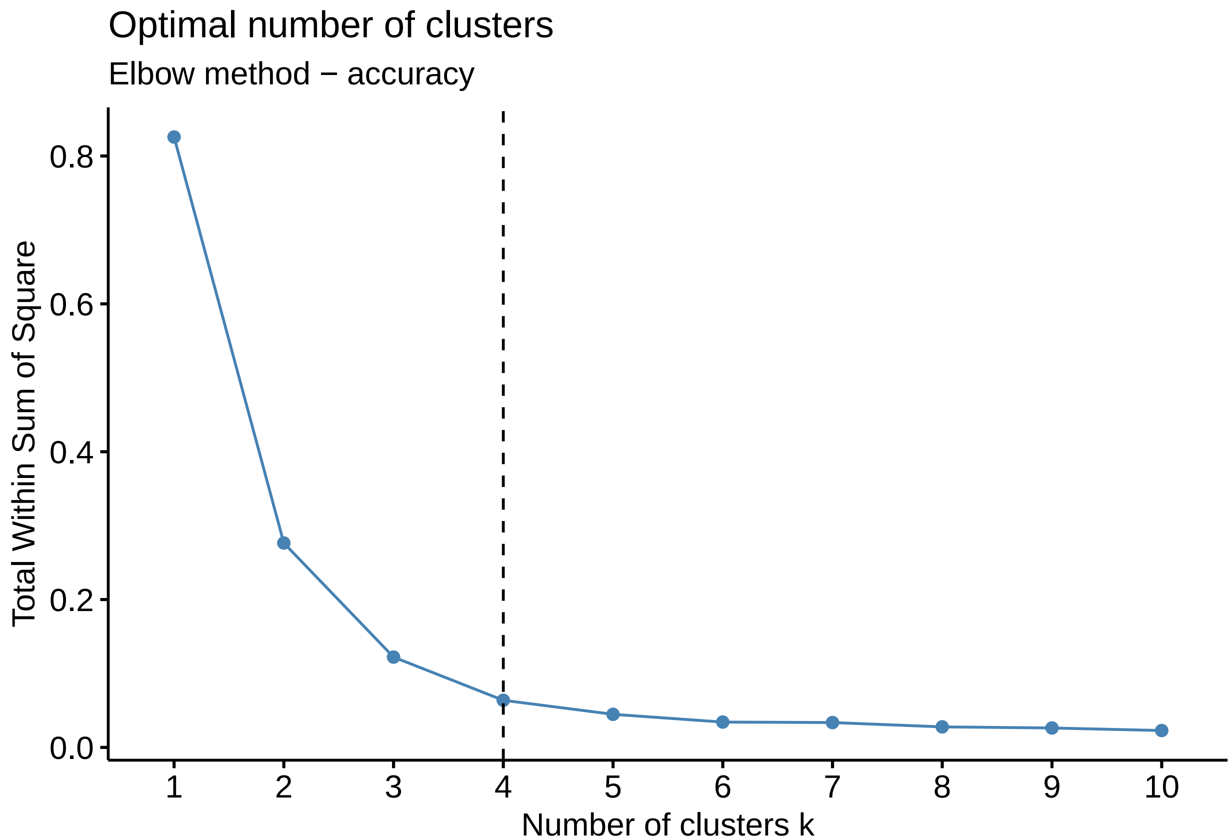
```
##   average    single  complete      ward
## 0.6361242 0.5132008 0.7165643 0.8340732
```




```
##  [1] 14 26 15 25 19 20 18 23 16 17 13 24 11 21  9 10  4  5  1  3  2  6  7  8 12
## [26] 22
```

```
##   average    single  complete      ward
## 0.4173949 0.2259740 0.5526253 0.7378997
```


0.8
0.6
0.4
0.2
0.0
a c e f b h j g d i q r w l v p s t u x k m y n o z


Optimal number of clusters
Elbow method − accuracy
Total Within Sum of Square
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0.4
0.6
0.8
1
2
3
4
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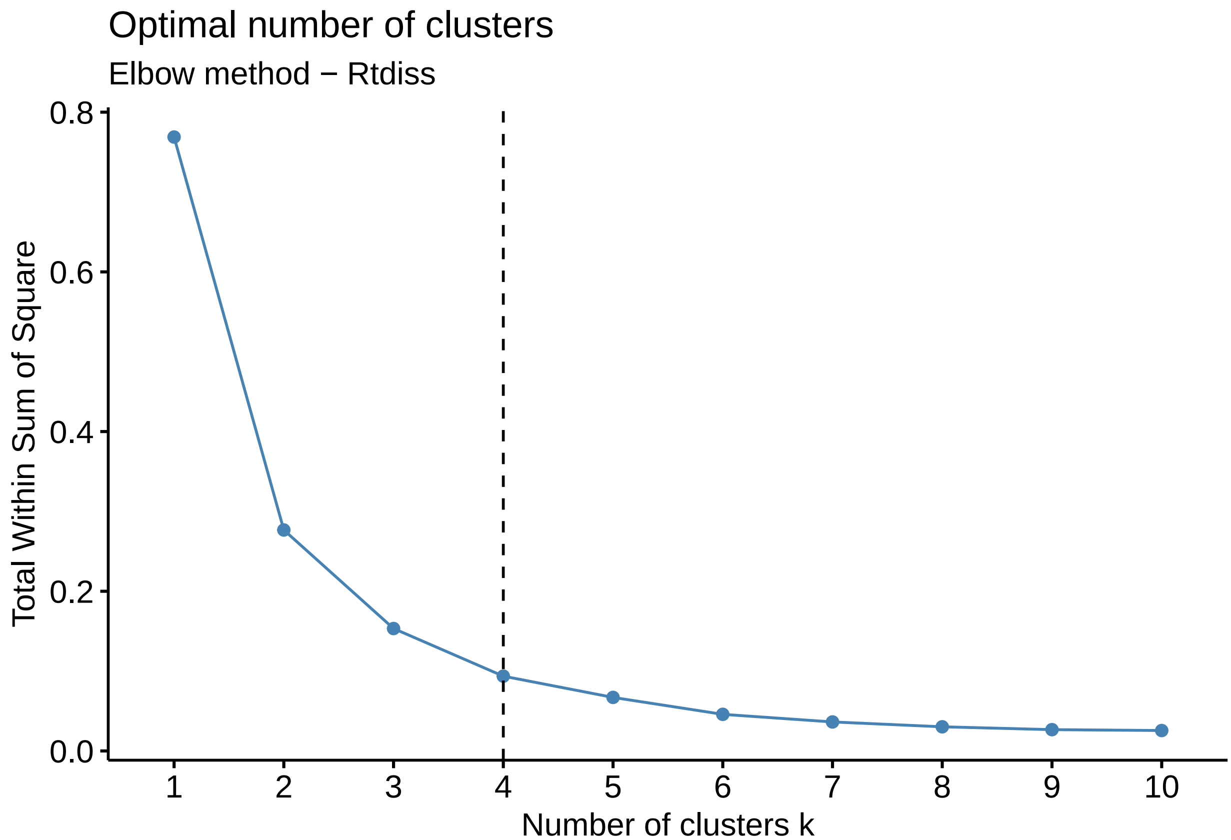
8
9
10
Number of clusters k


Optimal number of clusters
Elbow method − Rtdiss
Total Within Sum of Square
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0.6
0.8
1
2
3
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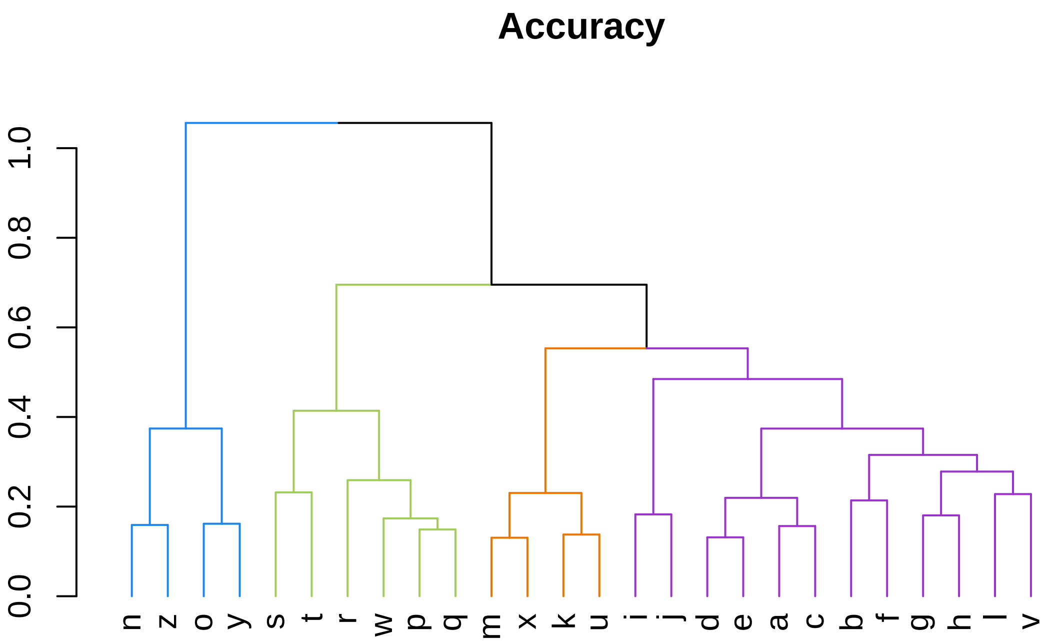
8
9
10
Number of clusters k



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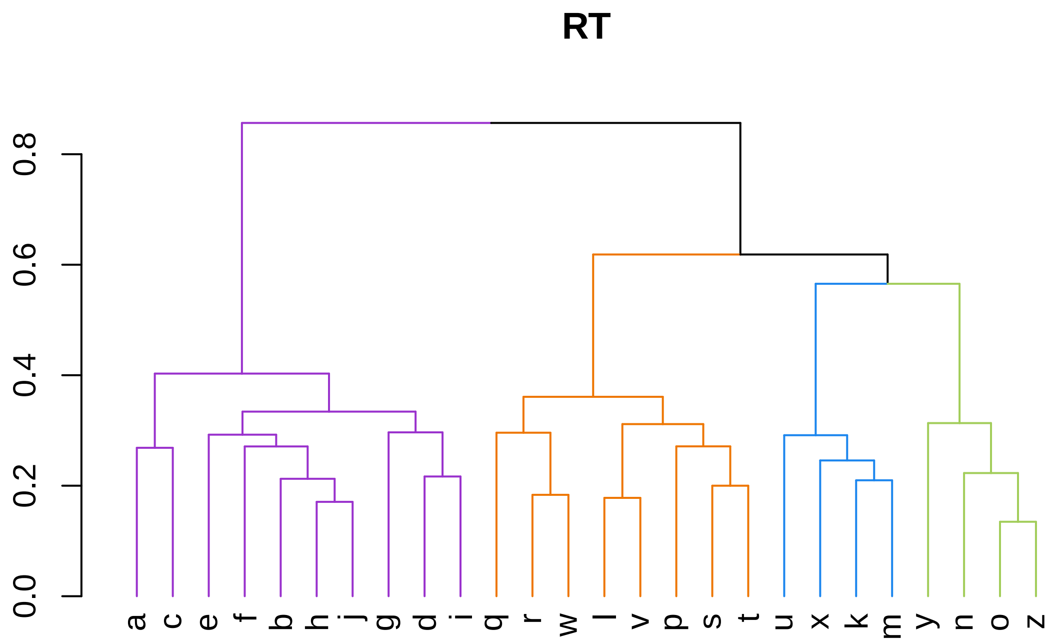

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266 **Discussion**

267 **General Discussion**

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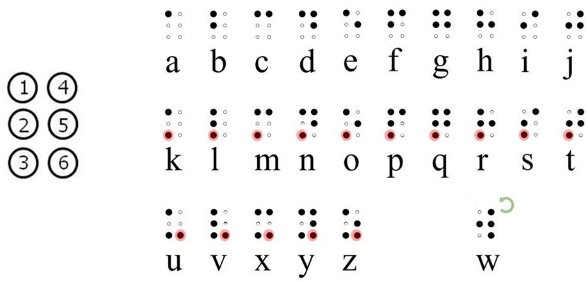

Figure 1