Appendix A: Signal Detection Theory (SDT) Analysis

How English orthographic proficiency modulates visual attention span in Italian learners with and without dyslexia

Venagli, I., Kupisch, T., Lallier, M.

D prime scores (d'), usually reflecting the sensitivity to detect the target, and decision bias (criterion C) per position were computed using the *dprime* function from the *psycho* package (Makowski, 2018) in R. The function calculates the proportion of HITS (YES responses when the target consonant was present in the string), MISSES (NO responses when the target consonant was present in the string), FALSE ALARMS (i.e., YES responses when the target consonant was not present in the string) and CORRECT REJECTIONS (i.e., NO responses when the target consonant was not present in the string). However, in the context of the present task, d' measures computed for each position cannot be considered as a pure sensitivity index. In fact, when computing d' for all five positions separately, we had to consider the same false alarm rate for all positions that was computed from all absent trials which cannot be assigned to specific position conditions. Therefore, these 'pseudo' d' values per position are not fully independent from response biases and should be interpreted in light of position-dependent C parameters. Therefore, these analyses will shed light on the modulation of spatial biases in the task affecting decision criterion towards more liberal (more probability to say YES to the presence of the target) or towards more conservative (more probability to say NO to the presence of a target) response strategies.

'Pseudo' d' and C scores were analysed as a function of Consonant Position, Group (TD vs. DYS), and English/Italian Orthographic Knowledge. The analysis was conducted with *lmer* models (*lme4* package, Bates et al., 2015), including a three-way interaction between the main effects listed above, and controlling for Phonological Short-Term Memory (Phonological STM). The models included random intercepts for Participants. The random effect structure was kept maximal (Barr et al., 2013), and thus allowed random slopes for Consonant Position over Participants. Random slopes were dropped in case of convergence issues. The *emmeans* and *emtrends* functions (*emmeans* package, Lenth, 2024) were used for the post-hoc analyses of interaction terms.

1. Effect of English orthographic knowledge on 'pseudo' d' and response biases (C criterion)

1.1. 'Pseudo' d'

The best-fit model included a three-way interaction between Consonant Position, Group and English Orthographic Knowledge, and a random intercept for Participants. The model yielded a significant effect of Group (χ^2 = 9.83, p = .002) and a significant three-way interaction between Group, Consonant Position, and English Orthographic Knowledge (χ^2 = 9.90, p = .042). Consonant Position alone was not significant (χ^2 = 3.02, p = .554), and neither was the effect of English Orthographic Knowledge (χ^2 = 2.75, p = .097). The model output is reported in Table A1, and the three-way interaction is plotted in Figure A1.

Formula: *lmer*(d' ~ Consonant Position * Group * EOK + Phonological STM + (1|ID))

	Chisq	*Df*	*p*
(Intercept)	65.61	1	< .001
EOK	2.75	1	.097
Consonant Position (CP)	3.02	4	.554
Group	**9.83**	**1**	**.002**
Phonological STM	0.03	1	.855
EOK * CP	3.25	4	.517
EOK * Group	**6.96**	**1**	**.008**
CP * Group	**12.67**	**4**	**.013**
EOK * CP * Group	**9.90**	**4**	**.042**

Table A1. Model output assessing the effect of Consonant Position (CP), English Orthographic Knowledge (EOK), and Group (DYS vs. TD) on 'pseudo' d' scores in the Visual 1-back task.

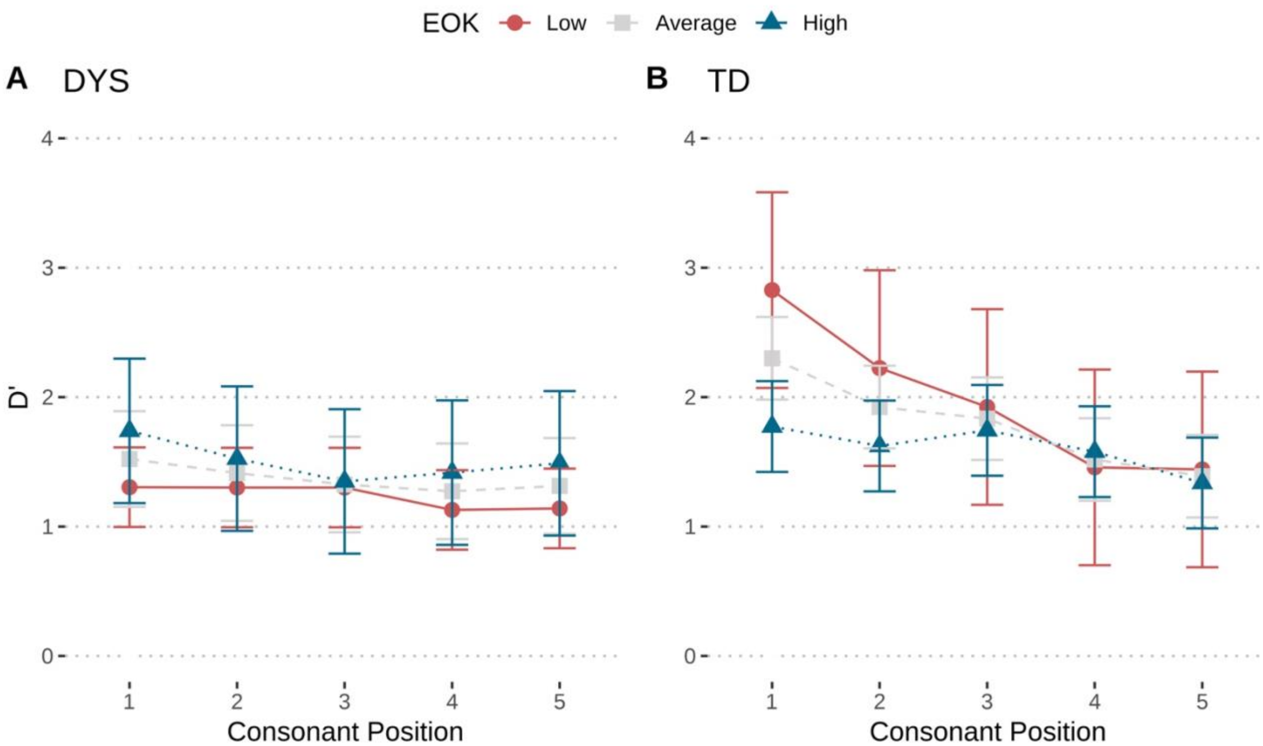

Figure A1. Effect of low (-1SD), average (M = 0), and high (+1SD) English Orthographic Knowledge (EOK) at each Consonant Position (CP) for DYS (A) and TD (B) participants.

The post-hoc analysis assessing the effect of English Orthographic Knowledge at each Consonant Position and for each Group showed that English Orthographic Knowledge played a significant, negative role when the consonant was presented in the first position, only for TD participants (Table A2). Further, we compared participants' performance at each consonant position in the string, and we found that differences between the rightmost and leftmost positions were only significant for TD participants, both at high and low proficiency levels (Table A3). Finally, to further explore the Group effect, we run a contrast analysis to compare DYS and TD participants' performance at each Consonant Position and level of English Orthographic Knowledge (LOW = -1SD, HIGH = +1SD). The analysis showed that TD participants had significantly higher d' scores as compared to DYS participants only at low English orthographic knowledge levels when the target consonant appeared in first (β = -1.52, *SE* = 0.41, *t* = -3.72, *p* < .001) and second position (β = -0.92, *SE* = 0.41, *t* = -2.26, *p* = .026), as reported in Table A4. The results are plotted in Figure A2.

Formula: *emtrends*(model, pairwise ~ CP | Group, var = "EOK", infer = T, adjust = "bonferroni")

CP	*Group*	*Estimate*	*SE*	*lower CL*	*upper CL*	*t*	*p*
1	DYS	0.22	0.13	-0.04	0.48	1.66	.099
2		0.11	0.13	-0.15	0.37	0.85	.395
3		0.02	0.13	-0.24	0.28	0.18	.857
4		0.14	0.13	-0.12	0.40	1.10	.274
5		0.17	0.13	-0.08	0.43	1.33	.186
1	**TD**	**-0.53**	**0.25**	**-1.03**	**-0.03**	**-2.09**	**.038**
2		-0.30	0.25	-0.80	0.20	-1.19	.234
3		-0.09	0.25	-0.59	0.41	-0.36	.720
4		0.06	0.25	-0.44	0.56	0.24	.810
5		-0.05	0.25	-0.55	0.45	-0.21	.836

Table A2. Effect of English Orthographic Knowledge (EOK) on TD and DYS participants' 'pseudo' d' scores by Consonant Position (CP).

Formula: *emmeans*(model, pairwise ~ CP | EOK | Group, at = list(EOK = c(-1,1), adjust = "bonferroni")

Contrast	*EOK*	*Group*	*Estimate*	*SE*	*df*	*t*	*p*
1CP – 5CP	Low (-1 SD)	DYS	0.16	0.13	304	1.25	.722
	High (+1SD)		0.25	0.25	304	1.01	.850
	Low (-1SD)	**TD**	**1.39**	**0.33**	**304**	**4.15**	**< .001**
	High (+1SD)		**0.44**	**0.15**	**304**	**2.92**	**.031**

Table A3. Comparison of DYS and TD performance in the leftmost vs. rightmost position (1CP – 5CP) at low (-1SD) and high (+1SD) English Orthographic Knowledge (EOK) levels.

Formula: *emmeans*(model, pairwise ~ Group | CP | EOK, at = list(EOK = c(-1,1), adjust = "bonferroni")

Contrast	*CP*	*EOK*	*Estimate*	*SE*	*df*	*t*	*p*
DYS - TD	**1**	**Low (-1SD)**	**-1.52**	**0.41**	**149.01**	**-3.72**	**< .001**
	2		**-0.92**	**0.41**	**149.01**	**-2.26**	**.026**
	3		-0.62	0.41	149.01	-1.52	.130
	4		-0.33	0.41	149.01	-0.80	.423
	5		-0.30	0.41	149.01	-0.74	.462
	1	High (+1SD)	-0.03	0.34	143.19	-0.10	.922
	2		-0.10	0.34	143.19	-0.29	.774
	3		-0.39	0.34	143.19	-1.16	.247
	4		-0.16	0.34	143.19	-0.48	.634
	5		0.15	0.34	143.19	0.45	.655

Table A4. Comparison of DYS vs. TD performance in all consonant positions (CP) at low (-1SD), average (*M* = 1) and high (+1SD) English Orthographic Knowledge (EOK) levels.

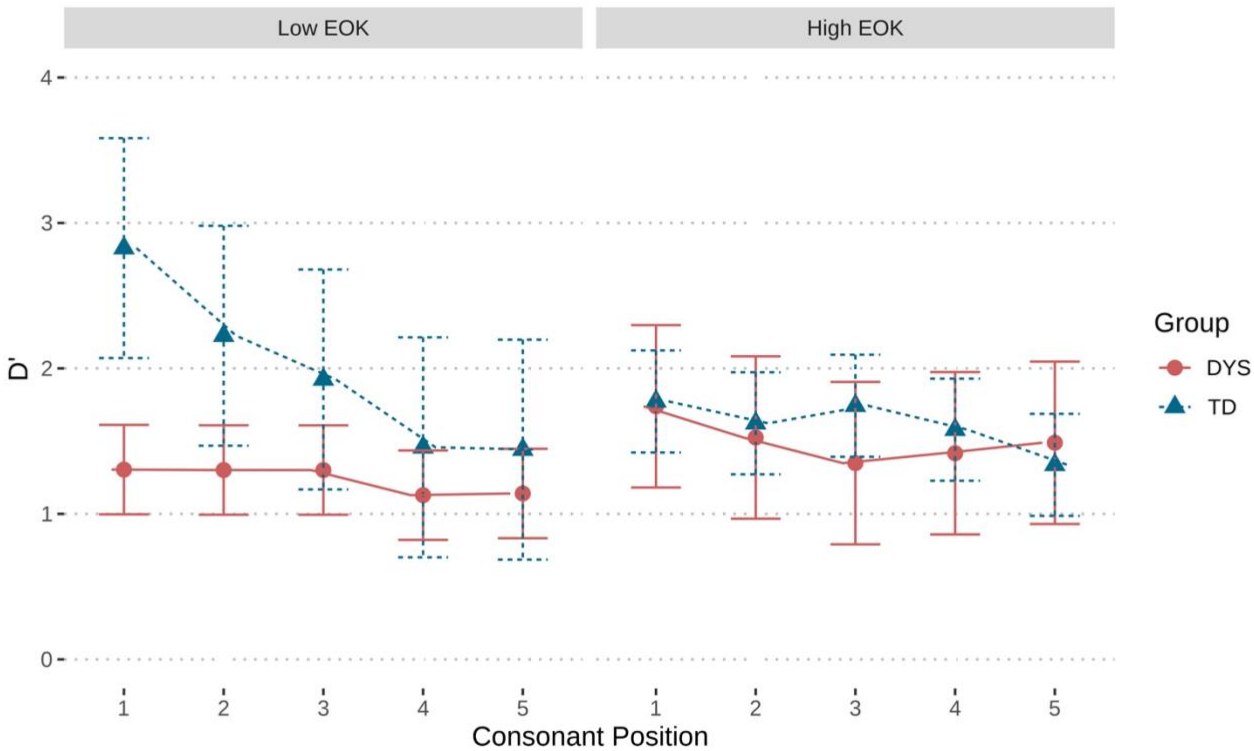

Figure A2. Comparison between DYS and TD performance at each Consonant Position (CP) and level of English Orthographic Knowledge (EOK): *Low EOK*: -1SD, *High EOK:* +1SD.

1.2. C criterion

The best-fit model investigating participants' response bias, as indexed by the criterion C in the SDT analysis, included a three-way interaction between English Orthographic Knowledge, Group (DYS vs. TD), and Consonant Position, while controlling for Phonological STM and individual variation (by including random intercepts for Participants). The model yielded a significant three-way interaction between Consonant Position, Group, and English Orthographic Knowledge ($\chi^2 = 9.90$, $p = .042$), but no independent variable was significant alone (Table A5). The interaction is plotted in Figure A3.

Formula: *lmer*(c ~ Consonant Position * Group * EOK + Phonological STM + (1|ID))

	Chisq	*Df*	*p*
(Intercept)	0.01	1	.941
English Orthographic Knowledge (EOK)	3.66	1	.056
Group	2.28	1	.131
Consonant Position (CP)	3.02	4	.554
Phonological STM	0.68	1	.411
EOK * Group	**4.51**	**1**	**.034**
EOK * CP	3.25	4	.517
Group * CP	**12.67**	**4**	**.013**
EOK * Group * CP	**9.90**	**4**	**.042**

Table A5. Model output assessing the effect of Consonant Position (CP), English Orthographic Knowledge (EOK), and Group (DYS vs. TD) on C criterion in the Visual 1-back task.

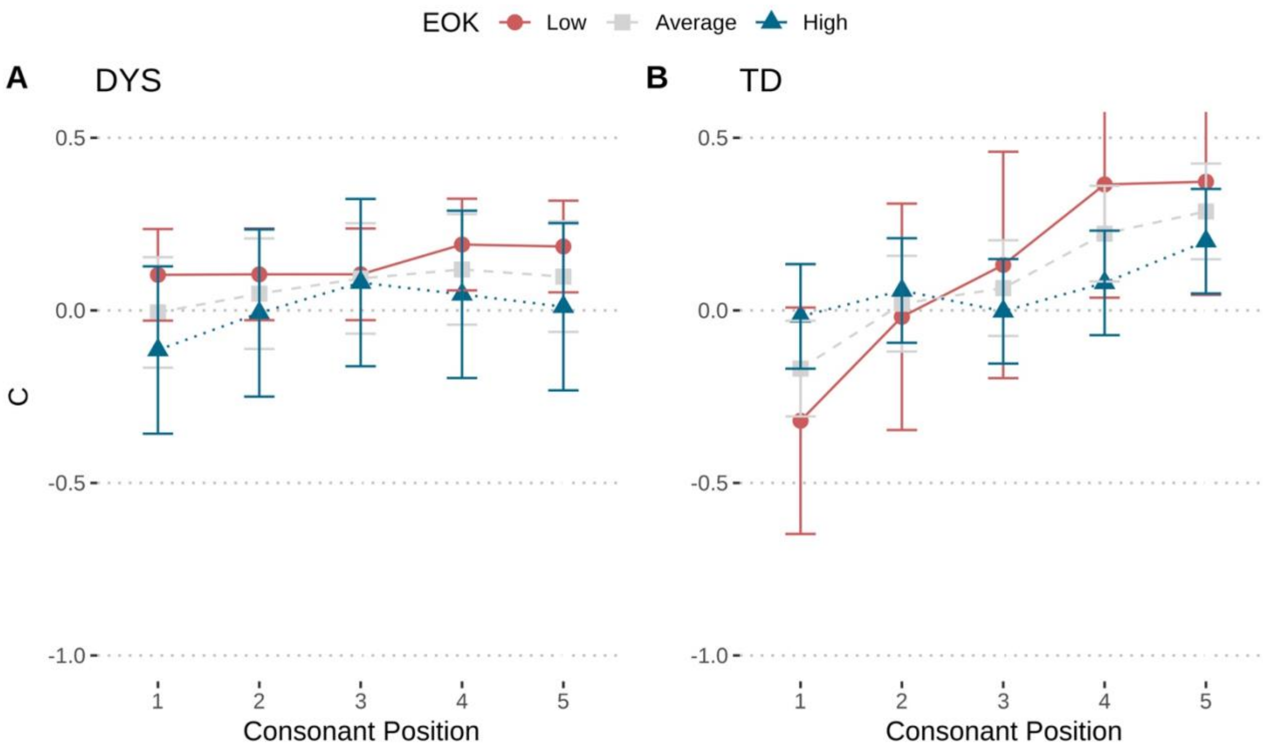

Figure A3. Effect of low (-1SD), average (*M* = 0) and high (+1SD) English Orthographic Knowledge (EOK) at each Consonant Position for DYS (A) and TD (B).

The post-hoc analysis investigating the effect of English Orthographic Knowledge at each Consonant Position and for each Group yielded no significant effect (Table A6), while the analysis contrasting participants' performance when the target was in the leftmost vs. rightmost position showed, once again, that the difference was only significant for TD participants, both at low ($\beta = -0.69$, $SE = 0.17$, $t = -4.15$, $p < .001$) and high ($\beta = -0.22$, $SE = 0.07$, $t = -2.92$, $p = .031$) English Orthographic Knowledge levels, albeit stronger in the former case (Table A7). Finally, we explored Group differences at each Consonant Position and levels of English Orthographic Knowledge (Table A8) and found that the response biases of DYS and TD participants only differed in the leftmost position, at low English Orthographic Knowledge level ($\beta = 0.42$, $SE = 0.18$, $t = 2.38$, $p = .018$), as illustrated in Figure A4.

Formula: *emtrends*(model, pairwise ~ CP | Group, var = "EOK", infer = T, adjust = "bonferroni")

CP	*Group*	*Estimates*	*SE*	*df*	*lower CL*	*upper CL*	*t*	*p*
1	DYS	-0.11	0.06	190.23	-0.22	0.00	-1.91	.057
2		-0.06	0.06	190.23	-0.17	0.06	-0.98	.326
3		-0.01	0.06	190.23	-0.12	0.10	-0.21	.833
4		-0.07	0.06	190.23	-0.18	0.04	-1.27	.207
5		-0.09	0.06	190.23	-0.20	0.03	-1.53	.127
1	TD	0.15	0.11	183.81	-0.06	0.37	1.39	.168
2		0.04	0.11	183.81	-0.18	0.25	0.35	.727
3		-0.07	0.11	183.81	-0.28	0.15	-0.62	.539
4		-0.14	0.11	183.81	-0.36	0.07	-1.31	.193
5		-0.09	0.11	183.81	-0.30	0.13	-0.79	.431

Table A6. Effect of English Orthographic Knowledge (EOK) on TD and DYS participants' response biases (criterion C) by Consonant Position (CP).

Formula: *emmeans*(model, pairwise ~ CP | EOK | Group, at = list(EOK = c(-1,1), adjust = "bonferroni")

Contrast	*EOK*	*Group*	*Estimates*	*SE*	*df*	*t*	*P*
1CP - 5CP	Low (-1 SD)	DYS	-0.08	0.07	304	-1.25	1.00
	High (+1SD)		-0.13	0.12	304	-1.01	1.00
	Low (-1SD)	**TD**	**-0.69**	**0.17**	**304**	**-4.15**	**<.001**
	High (+1SD)		**-0.22**	**0.07**	**304**	**-2.92**	**.038**

Table A7. Comparison of DYS and TD performance in the leftmost vs. rightmost position (1CP – 5CP) at low (-1SD) and high (+1SD) English Orthographic Knowledge (EOK) levels.

Formula: *emmeans*(model, pairwise ~ Group | CP | EOK, at = list(EOK = c(-1,1)), adjust = "bonferroni")

Contrast	*CP*	*EOK*	*Estimates*	*SE*	*df*	*t*	*p*
DYS - TD	**1**	**Low (-1SD)**	**0.42**	**0.18**	**190.96**	**2.38**	**.018**
	2		0.12	0.18	190.96	0.69	.490
	3		-0.03	0.18	190.96	-0.15	.879
	4		-0.17	0.18	190.96	-0.98	.329
	5		-0.19	0.18	190.96	-1.06	.292
	1	High (+1SD)	-0.10	0.15	182.23	-0.66	.508
	2		-0.07	0.15	182.23	-0.44	.657
	3		0.08	0.15	182.23	0.57	.572
	4		-0.03	0.15	182.23	-0.23	.821
	5		-0.19	0.15	182.23	-1.29	.197

Table A8. Comparison of DYS vs. TD performance in all Consonant Positions (CP) at low (-1SD), average (*M* = 1) and high (+1SD) English Orthographic Knowledge (EOK) levels.

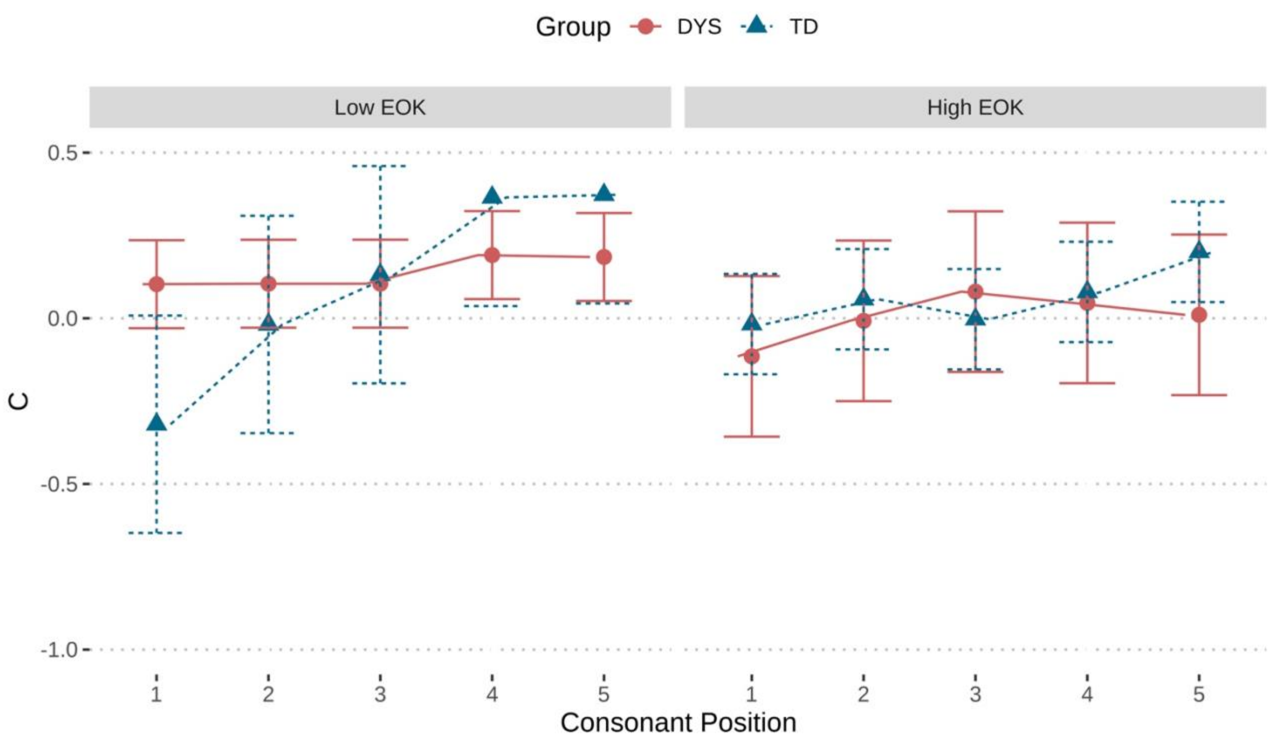

Figure A4. Comparison between DYS and TD performance at each Consonant Position (CP) and level of English Orthographic Knowledge (EOK): *Low EOK*: -1SD, *High EOK:* +1SD.

2. Effect of Italian orthographic knowledge on ‘pseudo’ d’ and response biases (C criterion)

2.1. ‘Pseudo’ d’

The best-fit model predicted d’ scores as a function of a three-way interaction between Italian Orthographic Knowledge, Consonant Position, and Group (DYS vs. TD), while controlling for Phonological STM. The model also included a random intercept for Participants. The model yielded a significant effect of Group ($\chi^2 = 10.96$, $p = .001$), but no other significant main effects (Table A9). The model output is illustrated in Figure A5.

Formula: *lmer*(d’ ~ Consonant Position * Group * IOK + Phonological STM + (1|ID))

	Chisq	*Df*	*p*
(Intercept)	29.80	1	< .001
Italian Orthographic Knowledge (IOK)	0.51	1	.477
Consonant Position (CP)	0.42	4	.981
Group	**10.96**	**1**	**.001**
Phonological STM	0.05	1	.827
IOK * CP	0.98	4	.913
IOK * Group	0.01	1	.914
CP * Group	8.21	4	.084
IOK * CP * Group	1.38	4	.848

Table A9. Model output assessing the effect of Consonant Position (CP), Italian Orthographic Knowledge (IOK), and Group (DYS vs. TD) on ‘pseudo’ d’ scores in the Visual 1-back task.

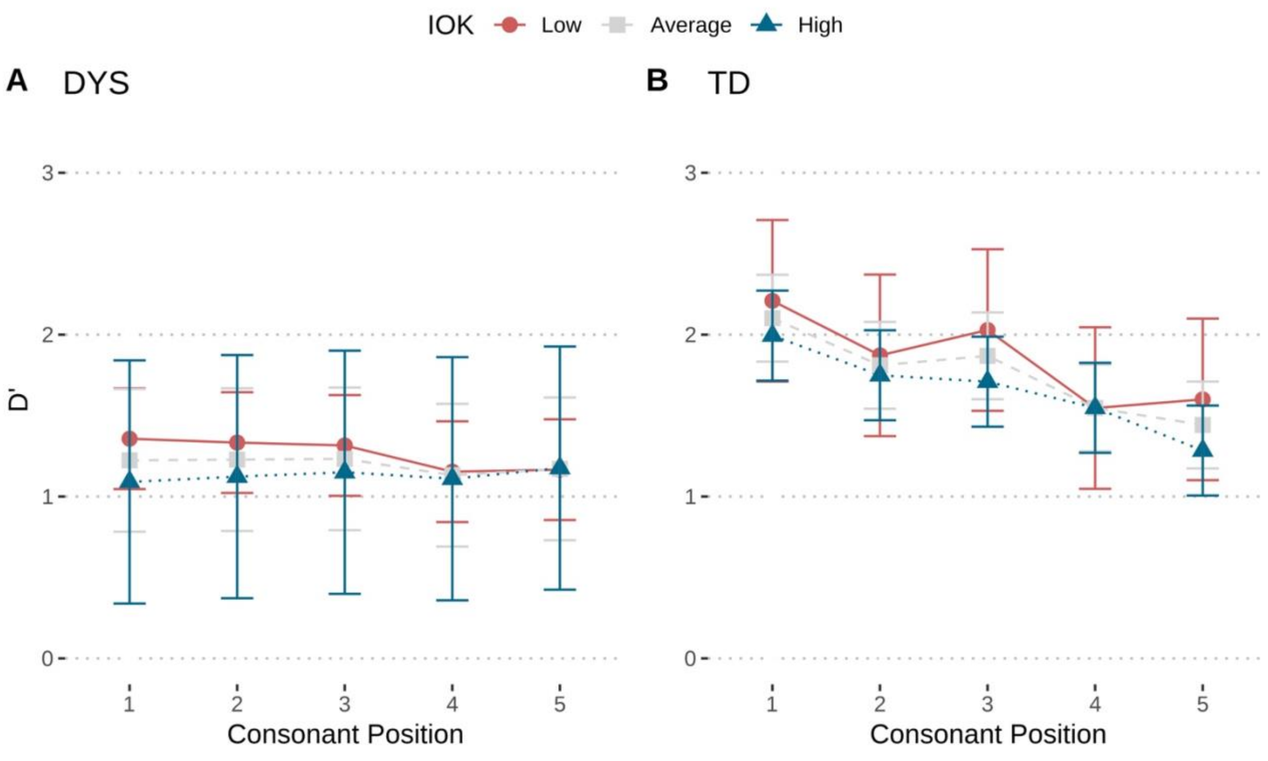

Figure A5. Effect of low (-1SD), average (M = 0) and high (+1SD) Italian Orthographic Knowledge (IOK) at each Consonant Position (CP) for DYS (A) and TD (B).

2.2. C criterion

The best-fit model investigating participants' response biases as a function of Italian Orthographic Knowledge yielded no significant effect (Table A10). The model output is illustrated in Figure A6 for comparative purposes.

Formula: *lmer*(c ~ Consonant Position * Group * EOK + Phonological STM + (1|ID))

	Chisq	*Df*	*p*
(Intercept)	0.92	1	.337
Italian Orthographic Knowledge (IOK)	0.03	1	.858
Group	3.17	1	.075
Consonant Position (CP)	0.42	4	.981
Phonological STM	1.20	1	.274
IOK * Group	0.04	1	.845
IOK * CP	0.98	4	.913
Group * CP	8.21	4	.084
IOK * CP * Group	1.38	4	.848

Table A10. Model output assessing the effect of Consonant Position (CP), Italian Orthographic Knowledge (IOK), and Group (DYS vs. TD) on C criterion in the Visual 1-back task.

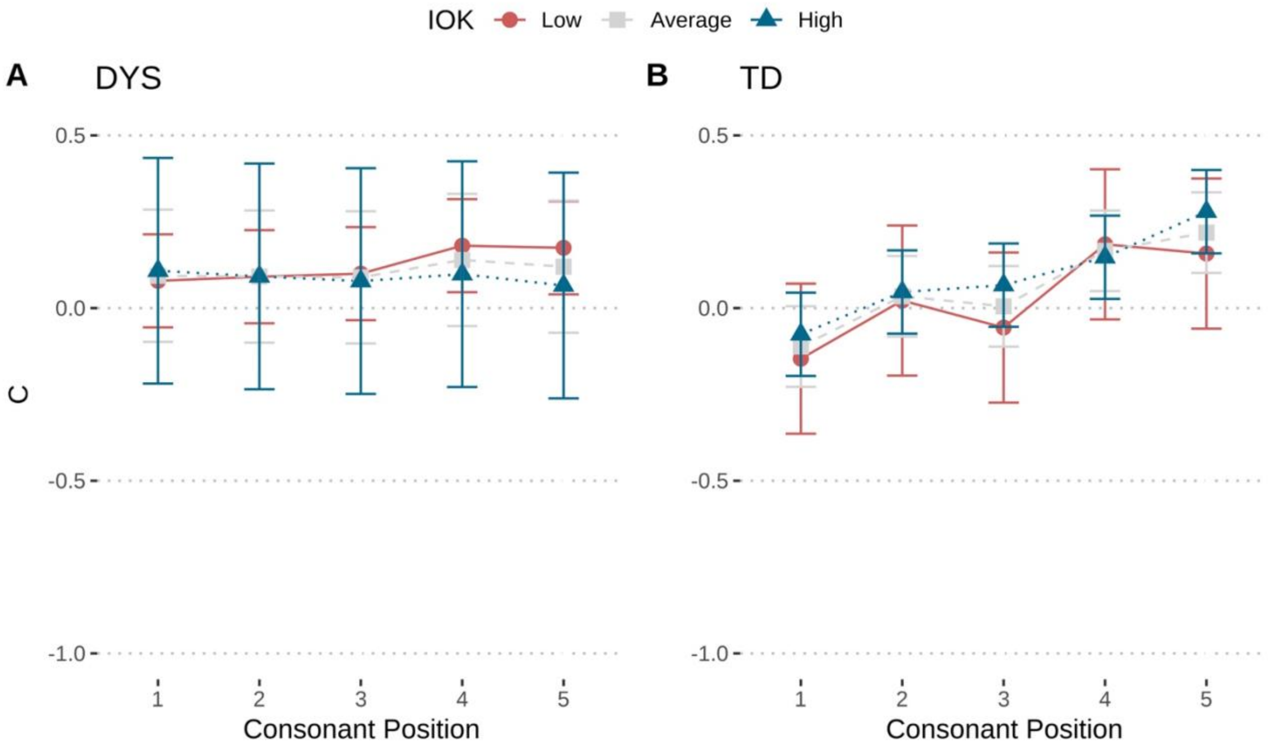

Figure A6. Effect of low (-1SD), average (*M* = 0) and high (+1SD) Italian Orthographic Knowledge (IOK) at each Consonant Position (CP) for DYS (A) and TD (B).

3. Discussion of results in light of accuracy data

The analysis on 'pseudo' d' and criterion C, both influenced by response biases, showed that the effect of English orthographic knowledge was significantly different for TD and DYS participants. Indeed, as argued previously, because of the intrinsic nature of our design, our 'pseudo' d' measures per position should be better interpreted as 'spatial attentional biases' influencing response strategies towards more liberal or conservative criterion rather than a pure measure of target detection sensitivity as classically viewed.

TD participants with low English orthographic knowledge appeared to bias their attention towards the leftmost position in the string, as indexed by higher 'pseudo' d' and lower C scores, as well as by higher accuracy scores, as discussed in the paper. Low C scores, along with high 'pseudo' d' scores, indicate a more liberal response bias (Stanislaw & Todorov, 1999), which leads to higher chances to say YES to the presence of a target even if it was absent. Interestingly, a comparison between the SDT analysis and the analysis of the accuracy data shows that a more liberal response bias was associated with higher accuracy when the target was presented in the leftmost position of the string. This suggests that TD participants with low English orthographic knowledge encoded the first letters in the string better, because they were significantly more biased to say YES to the presence of the target at these leftmost positions, which we interpret as a bias towards allocating attentional resources towards these positions. However, when the consonant was in the rightmost position, low-proficiency TD participants were more conservative, as indexed by significantly lower d' scores and significantly higher C scores (Table A3 and Table A7). Combined with accuracy data, showing that they were significantly less accurate when target consonants appeared in the rightmost position, these results suggest a failure in encoding the rightmost letter because of more conservative response biases. We suggest that conservative response biases may reflect target detection difficulties, possibly due to the lack of attention allocation towards the rightmost position in the string.

On the contrary, TD participants with high English proficiency seem to show such attention allocation and response biases that were more homogeneous across all positions. In addition to accuracy scores being equally high at all consonant positions, the 'pseudo' d' analysis suggests that higher English orthographic knowledge significantly reduces d' scores in the leftmost position (Table A2): this implies that as reading proficiency increases in English, participants are less biased to focus their attention on the leftmost letter in the string. The C criterion analysis also suggests that high-proficiency participants were overall more liberal across all positions. Taken together, these results suggest that higher English orthographic knowledge modulates response biases guided by positional information in the string in typical readers. These findings, along with the accuracy results presented in the paper, can be interpreted in line with modulations of attentional biases in the task as suggested by Lallier et al. (2016): while low-proficiency participants seem to strongly bias their attention towards the left side of the string, high-proficiency participants seem to distribute attention resources more homogeneously. This supports the hypothesis that acquiring a (non-native) opaque orthography could alter participants' visuospatial sensitivity to orthography-specific 'statistical regularities'. As a result, they may allocate more attention to the final letters of the string, recognizing the need to process larger visual units when dealing with opaque writing systems.

As for DYS participants, English proficiency did not appear to influence their response biases, neither in the 'pseudo' d' or criterion C analyses. Together with the accuracy data, these results suggest that the cognitive priors modulating processing and attention biases are less flexible in DYS, and thus less likely to be subject to cross-linguistic modulations, further supporting the claim that this may be due to a deficit at the VAS level (Valdois, 2022). As for group differences, accuracy data show that significant differences between TD and DYS only emerged when the target appeared in the rightmost positions of the string, and only when English orthographic knowledge was considered. In line with this, the analysis of 'pseudo' d' score showed that at low levels of English orthographic proficiency, TD participants bias their attention significantly more strongly towards the leftmost positions, while DYS participants' attention bias seems to not be modulated by English orthographic proficiency, regardless of target position. Similarly, analyses on C scores revealed that DYS were significantly more conservative when the consonant appeared in the leftmost position, but only at low orthographic proficiency levels in Italian. This result, together with the lack of position effect on C scores, further support the claim that DYS participants' visuo-spatial priors are less likely to be modulated by proficiency in an opaque (non-native) orthography, thus indicating a less malleable and more rigid visuo-spatial attentional strategies.

Finally, 'pseudo' d' scores and C scores were also analysed as a function of Italian orthographic proficiency. D' analyses confirmed the significant group effect observed above, with DYS being significantly less able to bias their attention than TD participants. Overall, the lack of significant effects of Italian orthographic proficiency goes in line with the accuracy analysis and support the hypothesis that transparent languages do not modulate VAS skills as strongly as opaque languages do.

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