# Chasing the Anchor:

**A Systematic Review and Meta-analysis of Perceptual Anchoring Deficits in Developmental Dyslexia**

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# Abstract

We report the results of a systematic review and meta-analysis investigating the relationship between perceptual anchoring and dyslexia. Our goal was to assess the direction and degree of effect between perceptual anchoring and reading ability in typical and atypical (dyslexic) readers. We performed a literature search of experiments explicitly assessing perceptual anchoring and reading ability using PsycInfo (Ovid, 1860 to 2020), MEDLINE (Ovid, 1860 to 2019), EMBASE (Ovid, 1883 to 2019), and PubMed for all available years up to June (2020). Our eligibility criteria consisted of English-language articles and, at minimum, one experimental group identified as dyslexic - either by reading assessment at the time, or by previous diagnosis. We assessed for risk of bias using an adapted version of the Newcastle-Ottawa scale. Six studies were included in this review, but only five (n = 280 participants) were included in the meta-analysis (we were unable to access the necessary data for one study).The overall effect was negative, large and statistically significant; *g* = -0.87, 95% CI [-1.47, 0.27]: a negative effect size indicating less perceptual anchoring in dyslexic versus non-dyslexic groups. Visual assessment of funnel plot and Egger’s test suggest minimal bias but with significant heterogeneity; Q (4) = 9.70, PI (prediction interval) [-2.32, -0.58]. The primary limitation of the current review is the small number of included studies. We discuss methodological limitations, such as limited power, and how future research may redress these concerns. The variability of effect sizes appears consistent with the inherent variability within subtypes of dyslexia. This level of dispersion seems indicative of the how we define cut-off thresholds between typical reading and dyslexia populations, but also the methodological tools we use to investigate individual performance.

*Keywords:* perceptual anchoring, dyslexia, reading impaired, perceptual learning

Perceptual anchoring can be defined as the implicit learning of regularities from an incoming perceptual stream (Ahissar, 2007). The term “anchor” has been attributed to the work of Harris (1948) in which she found that psychoacoustic protocols including repeated, or reference, tones yielded more-accurate performance relative to protocols without repeated tones. Hence, following cross-trial comparisons, an external reference is replaced by an internal reference, leading to increased response accuracy. In contrast, trials without a repeated reference do not promote increased performance. This trend in performance is comparable to that seen in perceptual learning paradigms in which increased exposure to perceptual information has a beneficial, long-lasting, impact on future decision-making. A small body of research has proposed a relationship between perceptual anchoring and developmental dyslexia (Ahissar, 2007; Banai & Ahissar, 2010).

Normal reading ability is situated on a continuum, the tail-end of which may be referred to as developmental dyslexia (herein “dyslexia”) (Shaywitz et al., 1992). Dyslexia is specified in terms of severity (American Psychiatric Association, 2013) and includes an impairment in one or more of the following reading abilities: grapheme-phoneme correspondence rules (i.e., sounding out words), word reading accuracy (i.e., reading words without error), reading rate or fluency (i.e., how quickly we read), and reading comprehension (i.e., understanding the meaning of what we read). Significantly, these deficits occur despite typical educational opportunity, and in the absence of any sensory or neurological damage (World Health Organization, 2018).

## Dyslexia vs. Dylexias

Traditionally, single or univariate theoretical approaches to dyslexia have opted to explain word-reading difficulties as the consequence of a disruption to some cognitive or perceptual process(es) (for review, see Parrila et al., 2017). These accounts may be broadly classified as: **phonological deficits**, in which word reading difficulty is explained via degraded phonological representations (i.e., phonological awareness, verbal short-term and working memory, and sometimes rapid automatized naming) (Snowling, 2000, 2001); **auditory processing deficits**, expressed as general auditory processing deficits which lead to reduced phonetic perception (Ahissar et al., 2000; Tallal, 1980) with noted extensions to the temporal domain (Goswami, 2011; Goswami et al., 2002); and **visual processing deficits**, expressed as reduced visual-spatial attention for single letters or letter strings (Livingstone et al., 1991; for review, see Skottun, 2000). The robustness of these accounts is generally quantified via associations between cognition/perception and reading performance. However, these univariate approaches are often unable to account for the heterogeneous nature of dyslexia and variable manifestations of reading difficulties (Parrila et al., 2017; Ramus & Ahissar, 2012).

## Perceptual Anchoring and Dyslexia

The perceptual anchoring deficit hypothesis, an extension of auditory processing deficit theories, is a more recent univariate approach to describing the cognitive/perceptual disruptions in dyslexia (Ahissar, 2007; Ahissar et al., 2006; Banai & Ahissar, 2006). The anchoring deficit hypothesis suggests that reading impairments in dyslexia may stem from an inability to adequately store, or ‘anchor’, perceptual information for later use. As previously described, anchoring occurs via regulated sequences of repeated inputs. This anchoring effect was initially demonstrated via a two-tone frequency-discrimination task whereby the inclusion of a reference condition, in which the first tone was identical across trials, benefitted typical but not dyslexic readers (Ahissar et al., 2006). This impairment was characterised as an increased threshold, as measured by the just noticeable difference, between tones averaged across all trials. Importantly, the performance of the dyslexic group within this reference condition was strongly correlated with their phonological memory, suggesting a common bottleneck between the two processes. As an extension to reading, these authors proposed that repeated exposure to phoneme-grapheme pairings may allow a learning reader to develop and adjust their responses to these inputs accordingly (Ahissar, 2007). The benefit of repeated exposure to these stimuli is solidified across development and helps demarcate between novice and expert level reading.

## Current Study

To date, and to our knowledge, there have been no literature reviews investigating perceptual anchoring in dyslexia. The aim of this review is to use the existing literature to characterise the effect between perceptual anchoring and dyslexia, and perform a meta-analysis. Measuring the veracity of these claims via narrative synthesis and meta-analysis will support continuing theoretical work investigating the causes of dyslexia, and potentially offer unique insight into the development of early detection tools.

# Method

This review was designed and reported in line with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA-P Group et al., 2015)

## Eligibility Criteria

To be marked eligible for inclusion in this review the work needed to be published in English.

### Participants

This review included studies across multiple demographics. Our aim was to cast a broad net in order to assess the current standing of literature studying the relationship between perceptual anchoring and dyslexia.

### Perceptual Anchoring Data

We included studies in which perceptual anchoring was explicitly measured using some form of perceptual based task.

### Reading Data

We included studies in which reading ability was defined as reading accuracy, reading fluency, reading skill, or reading comprehension.

### Exclusionary Criteria

Any study not published in English.

### Information Sources

We conducted the literature-search strategy with the above-mentioned terms with the goal of capturing the relationship between perceptual anchoring and dyslexia. We searched PsycInfo (Ovid, 1860 to 2020), MEDLINE (Ovid, 1860 to 2019), EMBASE (Ovid, 1883 to 2019), and PubMed for all available years up to June, 2020. The literature search was limited to human participants. The following is an example of the search strategy conducted in PsycINFO, “(percept\* adj1 anchor\*) or (percept\* adj1 learn\*) or (anchor\* adj1 deficit) or (statistical adj1 learning AND (read\* adj1 abi\*) or (dyslexi\* or (poor adj1 read\*) or ((read\* or learn\*) adj1 (dis\* or diff\* or impair\* or def\* or delay))).”

### Study Selection

The articles were screened in five Steps, using SYRAS (Jones & Badcock, 2017), a systematic review assistant and data management web-based application. In Step 1, search terms were entered into pre-selected databases and citations were downloaded. In Step 2, citations were uploaded to SYRAS and duplicates were discarded. In Step 3, all titles and abstracts were screened by the two authors, with titles and/or abstracts including reference to association between perceptual anchoring and reading ability (see Appendix A for search terms) included for further evaluation. In Step 4, both authors independently screened the remaining articles, and discussed discrepancies between selected articles. In Step 5, the full text of included articles from Step 4 were assessed for eligibility by KDS. Where there was ambiguity regarding the inclusion of a selected work, the text was discussed by both authors. The rationale for excluded works was recorded (see Appendix B for Step 5 exclusions). Up to Step 3, both authors were blind to journal titles, study authors, and institutions.

## Data Extraction

The data were extracted from each of the selected works and entered into a customized Word document (see Appendix C). The data included demographic information, perceptual measures used and outcomes, and reading assessments and outcomes. In instances where required data was missing, contact with the appropriate author was attempted and additional information requested. If there was no response from the author, or the data was unavailable, we excluded the study from the meta-analysis (one study was excluded based on this criteria) but included in the narrative review.

## Appraisal of Methodological Quality

To assess the risk of bias for each study, we used an adapted version of the Newcastle-Ottawa Scale (Wells et al., 2012) (Appendix D). We awarded each work a maximum of 21 points in relation to the following constructs: Representativeness of the sample (0 to 3), Sample size (0 to 1), Sample quality (1 to 3), Assessment of outcome for each of perceptual and reading measure (1 to 4), and Statistical-test quality for each of the perceptual and reading measures (1 to 3). These ratings were made independently by both authors and any discrepancies were discussed until agreement was reached. The evidence was evaluated based on three tiers of quality ratings: high (15 to 21 points), medium (8 to 14), and low (1 to 7). The greatest weight for conclusions was based on the high-quality papers, followed by medium, and low. If the conclusions were consistent between these tiers, then we concluded the literature to be limited in terms of bias.

## Data Analysis

The results of the individual studies measuring the relationship between perceptual anchoring and dyslexia were meta-analysed using a combination of packages through statistical and data analysis software R (R Core Team, 2019): meta (Schwarzer, 2007); metaphor (Viechtbauer, 2010); dmetar (Harrer et al., 2019); MOTE (Buchanan et al., 2019); and an Excel effect size calculator (From\_R2D2; Lakens, 2013). We calculated Hedge’s *g* effect sizes using effect size calculators in MOTE (Buchanan et al., 2019) and From\_R2D2 (Lakens, 2013) based on the reported statistics (i.e., F-statistic and degrees of freedom). Effect sizes reflected the degree of difference between groups (control vs. dyslexia) and within the condition of interest (no reference vs. reference). Hence, negative effect sizes were interpreted as showing less anchoring for dyslexia relative to control groups. Hedge’s *g* was interpreted as small (0.20), moderate (0.50), and large (0.80; Cohen, 1988, 1992) . We elected for the use of Hedge’s *g* as it provides a more conservative effect-size estimate in small sample sizes (Hedges & Olkin, 1985). We used a random-effects model for our meta-analysis. We selected this model for two reasons: the substantial variability between populations sampled, and for the relatively small number of studies included in our analysis (Schwarzer et al., 2015). Further, and in respect to the latter point, we applied the Sidik-Jonkman method with a Hartung-Knapp adjustment to decrease the possibility of Type 1 errors (Röver et al., 2015). A test of heterogeneity was also performed in which we quantified heterogeneity using *T*, *T2*, *I2*and the prediction interval (PI): *T* (Tau), the estimated standard deviation of true effects across studies; *T2* (Tau-squared), the variance of the true effects across studies and *I2* (I-squared), the percentage of the variability in effect estimates due to heterogeneity (M Borenstein et al., 2009; Deeks et al., 2008).

# Results

## Study Selection

Our initial search identified 1918 articles (Figure 1). After the removal of 573 duplicates, the titles and abstracts of the remaining 1345 articles were screened. This resulted in 195 articles that were deemed potentially relevant to our review. Further screening (Step 3) led to the exclusion of another 187 articles leaving 8 articles of to be reviewed in their entirety. Discrepancies between these selections were discussed (Step 5) and an additional 2 articles were excluded, leaving a total of 6 articles.

## Risk of Bias within Studies

A total of 86 points were awarded (see Table 1). Of those studies, four out of six were evaluated as medium quality. The remaining two papers were evaluated as high quality.

Records identified through database search

(n = 1918)

Records after duplicates removed

(n = 1345)

Additional records identified through other sources

(n = 0)

Records screen

(n = 1345)

Records evaluated by both authors

(n = 195)

Records excluded

(n = 1150)

Records excluded

(n = 187)

Full-text articles assessed for elgibility

(n = 8)

Full-text articles excluded and rationale reported

(n = 2)

Studies included in qualitative synthesis

(n = 6)

Studies included in quantitative synthesis

(n = 5)

**Figure 1** *Iterative process of record inclusion/exclusion*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Article | Sample Characteristics | | | Perceptual Measures | | Reading Measuers | | Total |
|  | Representativeness | Size | Quality | Measure-Assessments | Statistical test evaluations | Measure assessments | Statistical test evaluations |  |
| Ahissar, 2006 | 1 | 0 | 1 | 3/4 | 3/3 | 3/4 | 3/3 | 14 |
| DiFillipo, 2008 | 3 | 0 | 3 | 4/4 | 2/3 | 3/4 | 3/3 | 17 |
| Oganian, 2010 | 2 | 0 | 1 | 3/4 | 2/3 | 3/4 | 3/3 | 14 |
| Wijnen, 2012 | 1 | 0 | 1 | 3/4 | 3/3 | 3/4 | 3/3 | 14 |
| Agus, 2014 | 2 | 0 | 1 | 3/4 | 3/3 | 4/4 | 3/3 | 15 |
| Daikhin, 2017 | 1 | 0 | 1 | 2/4 | 2/3 | 3/4 | 3/3 | 12 |
|  |  |  |  |  |  |  |  | 86 |

**Table 1** *Risk of bias totals*

## Study Characteristics

### Study Location

Out of the six studies, three were completed in Israel (Ahissar et al., 2006; Daikhin et al., 2017; Oganian & Ahissar, 2012), one in Italy (Di Filippo et al., 2008), one in France (Agus et al., 2014), and one in the Netherlands (Wijnen et al., 2012). Two studies recruited participants through the primary author’s affiliated university (Daikhin et al., 2017; Oganian & Ahissar, 2012), one recruited through a private school (Ahissar et al., 2006), one through a public school (Di Filippo et al., 2008), and the remaining recruited through local universities (Agus et al., 2014; Wijnen et al., 2012).

### Measuring Perceptual Anchoring Ability

The tasks used to assess perceptual anchoring varied between studies. Three studies used auditory frequency discrimination tasks (Ahissar et al., 2006; Oganian & Ahissar, 2012; Wijnen et al., 2012); one used rapid automatized naming (Di Filippo et al., 2008); and two used a novel, repeated-noise detection task (Agus et al., 2014; Daikhin et al., 2017).

#### **Frequency discrimination task.**

Frequency discrimination tasks consisted of two conditions using a two-interval, two-alternative, forced-choice (2AFC) paradigm. Participants indicated which of two tones was higher in pitch. In one condition (‘standard’), the frequency of a fixed reference pure tone (1000 Hz) was constant across all trials. In the other condition (‘no-standard’ or ‘roving’), no fixed reference tone was used, instead, the lower tone was randomly selected every trial from a defined interval. The frequency of the higher tone was determined based on participant’s performance on the previous trial. Tone duration was 50 ms, initial-frequency difference was 500 Hz, and inter-stimulus interval was 950 ms (Ahissar et al., 2006).

#### Rapid automatized naming task (RAN).

The RAN task consisted of two conditions using two sets of stimuli (objects and numbers). In the small-set condition, five repeated items were used. In the large-set condition, an open list of 50 non-repeated stimuli was used. Each set consisted of a matrix of ten rows with five stimuli per row, for a total of 50 items. For objects, the small set consisted of a book, table, needle, bag and house, and the large set consisted 50 non-repeated items. For numbers, the small set consisted of the sequence 2, 4, 5, 7 and 9, and the large set consisted of 50 non-repeated numbers ranging between 10 and 99 (Di Filippo et al., 2008).

#### Repeated noise detection task.

The repeated-noise detection task consisted of three conditions, using a 2AFC paradigm. Participants were presented with a 1 s white-noise token and indicated whether the noise contained a repetition. White-noise tokens were generated as independent, normally-distributed random numbers. Participants were presented with either a noise token (N: 1 s of continuously generated white noise), a repeated-noise token (RN: 1 s of white noise split in half and the first half concatenated to itself), and a reference repeated-noise token (RefRN: generated as the RN stimuli but was repeated within a block). In a block of 80 trials, 40 trials were N stimuli, 20 were RN, and 20 were RefRN. Different RefRNs were presented across block (Agus et al., 2010, 2014).

### Measuring Reading Ability

Reading measures also varied between studies. Ahissar et al. (2006) measured non-word reading (accuracy and rate) and phonological awareness (spoonerism accuracy and word segmentation) using a word list designed and evaluated specifically for Hebrew reading participants (Deutsch & Bentin, 1996), and a Hebrew version of the spoonerism task (unpublished test material), respectively. Di Filippo et al. (2008) measured reading level using a standardized Italian reading achievement test (MT Reading test; Cornoldi & Colpo, 1992) whereby accuracy and rate were assessed. Oganian and Ahissar (2012) measured non- and real-word reading with the identical measure to Ahissar et al. (2006). Agus et al. (2014) measured reading using a standardized French reading test, “L’alouette” (Lefavrais, 1967), whereby accuracy and rate were assessed, and a French spoonerism task (composite score from accuracy and rate). Finally, Daikhin et al. (2017) measured non- and real-word reading with an identical set of measures to Ahissar et al. (2006).

Cut-off scores used to designate dyslexia-like reading performance varied between studies. Ahissar et al. (2006) used a phonological score (see above for specific measures) of less than 1.5 standard deviations (SD), or more, below the mean of the control sample to classify participants as dyslexic. Di Fillipo et al. (2008) used an accuracy or rate score of less than 2 s.d, or more, below the mean of the control sample to classify participants as dyslexic. Oganian and Ahissar (2012) converted reading scores to z-scores for accuracy and rate; the hyper-link provided for these population norms is no longer live and no cut-off score was explicitly provided in the publication. Wijnen et al. (2012) included only participants who had been diagnosed by a certified psychologist and reading scores were average scores based on reading measures which were converted to a standard score. No cut-offs were explicitly provided in this publication nor were the criteria used to diagnose dyslexia in instances of professional assessment. Agus et al. (2014) used a reading fluency score (average of reading rate and accuracy) as well as eligibility criteria that included a history of reading difficulties at school age and fluency score below the level of eighth grade. Finally, Daikhin et al. (2017) did explicitly provide a cut-off threshold for designating groups, but did capture performance via accuracy and rate scores.

### Miscellaneous Measures

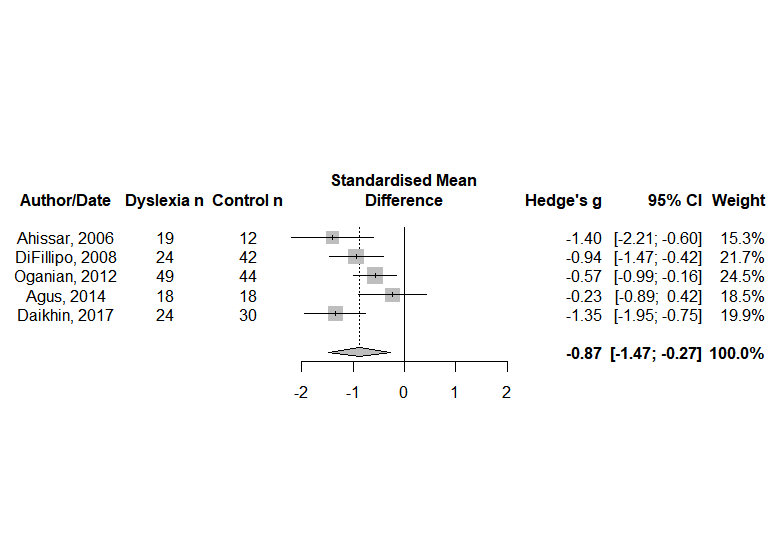
Although not of interest to this review, each study assessed at least one additional aspect of cognitive functioning. Five out of six studies (Agus et al., 2014; Ahissar et al., 2006; Daikhin et al., 2017; Oganian & Ahissar, 2012; Wijnen et al., 2012) measured verbal working memory with the Digit-span subtest of the WAIS-III (Wechsler, 2000), and five out of six studies measured visuospatial reasoning with Block Design (Ahissar et al., 2006; Daikhin et al., 2017; Oganian & Ahissar, 2012), Picture Completion, and Matrices (Agus et al., 2014) subtests of the WAIS-III (Wechsler, 2000), and/or Raven’s Coloured Progressive Matrices (Agus et al., 2014; Di Filippo et al., 2008; Raven et al., 2003).

## Participant Characteristics

All studies reported age. The mean age of the dyslexic groups was 19.96 (SD = 5.9, mean range: 11.7 to 24.8) years and controls 20.10 (SD = 6.16, mean range: 11.8 to 25.9) years. The proportion of males (52.2% and 52.7%) to females (58.2% and 57.3%) for dyslexia and controls groups were similar, respectively. No studies reported ethnicity. All studies reported the language used for assessment and in all cases, this was identical to language spoken. Three studies were conducted in Hebrew (Ahissar et al., 2006; Daikhin et al., 2017; Oganian & Ahissar, 2012), one study in Italian (Di Filippo et al., 2008), one study in Dutch (Wijnen et al., 2012), and one in French (Agus et al., 2014). In two studies, the poor-reading group comprised of participants previously diagnosed with a reading impairment (Oganian & Ahissar, 2012; Wijnen et al., 2012). All studies included an assessment of sensory modality required for perceptual measure. Four studies required a self-report of history of normal/typical hearing (Agus et al., 2014; Ahissar et al., 2006; Daikhin et al., 2017; Wijnen et al., 2012), one completed basic audiometry (Oganian & Ahissar, 2012), and one required a self-reported history of normal/typical vision (Di Filippo et al., 2008).

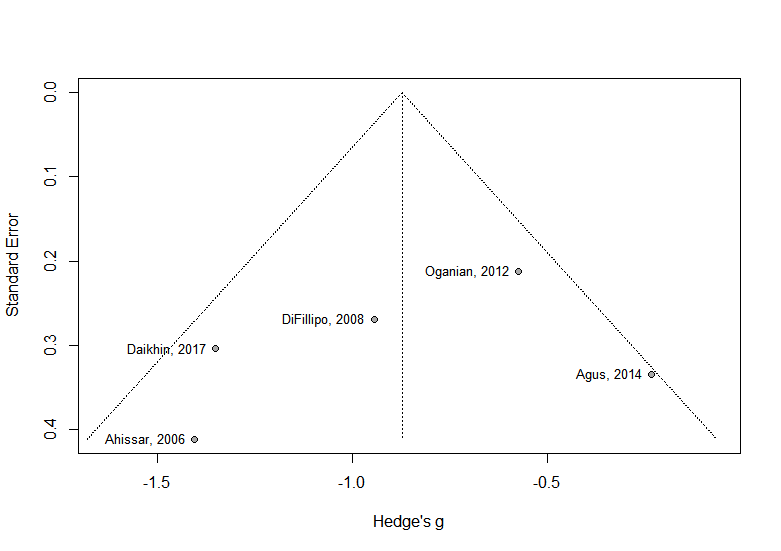
## Meta-analysis of Perceptual Anchoring in Dyslexia

Of the six studies, five provided data for dyslexia and control groups on perceptual anchoring tasks. One study (Wijnen et al., 2012) was excluded as authors did not report the necessary data and did not respond to communications. Figure2 shows the effect sizes from five studies contrasting the standardised mean difference and 95% CIs between dyslexia and controls groups on measures of perceptual anchoring (dyslexia n = 134, mean sample size = 26.8; control n = 146, mean sample size = 29.2).



**Figure 2** *Forest plot showing included studies of the meta-analysis and sample sizes per group and study.*

The overall effect was negative, large and statistically significant; g = -0.87, 95% CI [-1.47, -0.27], p < 0.05. A test of heterogeneity suggests that the effect sizes significantly varied across studies; Q (4) = 9.70, PI [-2.32, 0.58], p < 0.05. We quantified this variation using; Tau = 0.40, Tau2 = 0.16 and I2 = 59%. We interpret the prediction interval as where we would expect true effect size to fall in 95% of future cases (Borenstein et al., 2017). Likelihood of bias across studies was inspected visually through a random-effects funnel plot (see Figure 3). The standardised mean difference (Hedge’s g) is plotted on the x-axis and the standard error plotted on the y-axis. The funnel plot appeared symmetrical, and evaluation of Egger’s test suggested minimal bias; intercept = -2.76, t(3) = -0.84, p = 0.47, 95% CI [-9.23,3.70].

**Figure 3** *Funnel plot of the standardized mean effect size (Hedge’s g) as a function of the standard error.*

# Discussion

The primary goal of this systematic review and meta-analysis was to assess the claim of perceptual anchoring deficits in dyslexia. Below, we discuss the results of our meta-analysis and how they may best be interpreted, the limitations of the current review, and critical reflection on the current state of perceptual anchoring research in dyslexia.

## Perceptual Anchoring and Dyslexia

The results of our meta-analysis revealed a significant and large effect of perceptual anchoring deficits in dyslexia, and the results from our test of heterogeneity suggest a significant level of variability in effect sizes across the included studies. Although the outcome of our review suggests that individuals with dyslexia, on average, perform more poorly on measures of perceptual anchoring, relative to those readers without dyslexia, a greater number of studies is needed to produce a more robust estimate of this effect.

## Limitations of the Current Review

The primary limitation of the current review is the small number of included studies; however, we feel this is not a sufficient reason to exclude the meta-analysis from our review. Common heuristics vary in terms of required studies with some estimates suggesting k > 10, but these estimates often fail to account for changes in the model’s power to detect an effect as the number of included studies vary (Valentine et al., 2010). Indeed, it has been proposed that meta-analyses of k ≥ 5 studies will likely yield an adequate increase in power for most random-effects models and should always be considered advantageous when interpreted appropriately (Jackson & Turner, 2017). The relative shortage of studies to synthesize can be partially accounted for by the novelty of perceptual anchoring studies but may also be accounted for by the fact that null findings are inaccessible to the broader research community due to publication bias. Visual inspection of funnel plots and statistical evaluation of the plot’s asymmetry are used to address the latter concern. The funnel plot and its evaluation in this meta-analysis do not imply bias. However, interpretation of this outcome should be done cautiously as the tests sensitivity to detect publication bias decreases when the number of included studies is small (see Egger et al., 1997; Higgins, 2008; Sterne et al., 2011). Further, given the variability in experimental design and sample demographics, the increased and significant level of heterogeneity between the included studies is unsurprising.

## Limitations of the Current Literature

In its inception, the anchoring effect was revealed via frequency discrimination tasks in which the inclusion of a reference pure tone benefited non-dyslexic listeners but not dyslexic listeners (Banai & Ahissar, 2006). Discussions following this predicted that impaired anchoring could account for the reduced performance in both auditory and visual modalities, attentional tasks and as a reinterpretation of phonological difficulties that are typically identified as the primary deficit for a substantial proportion of the dyslexic population (Ahissar, 2007). Investigations into these predictions, several of which are included in this review, have addressed the perceptual anchoring deficit hypothesis through divergent experimental designs. However, one advantage in performing a meta-analysis is that these discrepancies may be overcome in order to more concisely quantify the relationship between our constructs of interest. The results from our meta-analysis, namely, that dyslexics are poorer than controls in their ability to anchor to frequently reoccurring stimuli should be considered evidence in support of the perceptual anchoring deficit hypothesis. However, a statement on the methodological limitations of the included studies is required.

First, although the measures used to investigate perceptual anchoring were theoretically informed, their outcomes are difficult to assess due to small sample sizes. Based on the use of a mixed-design ANOVA with manipulated factors, and assuming the researchers were interested in finding a moderate effect (*f* = 0.25) with an alpha level of 0.05, a total sample size of 128 (64 per group, assuming two groups) would be required in order to achieve power of 0.80 (G\*Power 3; Faul et al., 2007). That is, assuming there is a true difference between the average performances of the two groups, you would expect to find it 80% of the time (Cohen, 1992). A post hoc power analysis revealed that, of the included studies, total sample sizes ranging from 31 – 93 achieved statistical power ranging from 0.34-0.79. Justifications for sample size limitations were provided in one study (Daikhin et al., 2017) and no power analyses were reported. This concern is compounded by replication efforts of underpowered designs that suffer from identical flaws (i.e., underpowered studies conceptually replicating underpowered studies). The above example of achieving 0.80 power may be incompatible with the resources available to many researchers. However, specifying and reporting the smallest effect size, and subsequent sample size, that still supports a hypothesis of interest aids the broader research community in evaluating and weighting experimental findings (Dienes, 2008; Goertzen & Cribbie, 2010; Harms & Lakens, 2018; Lakens, 2013). Recently, practical efforts have been made to help develop statistical inferences following null findings such as by the use of equivalence testing and Bayes Factors (Lakens et al., 2018, 2020). The application of such techniques would allow for a more robust interpretation of null findings and would aid in further specifying the extent and nature of perceptual anchoring deficits in subgroups of the dyslexia population.

Second, a criticism of the anchoring deficit hypothesis is that such a univariate account of impairment is unable to adequately address the highly heterogeneous presentation of deficits in the dyslexia population (Wijnen et al., 2012). One response to the heterogeneity of word-reading difficulties within the dyslexia population has been through subtyping. Subtyping relies on a combination of theoretical accounts used to describe the cognitive disruptions that may lead to variable word-reading difficulties (Castles & Coltheart, 1993; Friedmann & Coltheart, 2018; McArthur et al., 2013; Parrila et al., 2017; Peterson et al., 2013; Ziegler et al., 2008; Zoubrinetzky et al., 2014). Subtypes include: letter position dyslexia, expressed as migrations of letters within words (Friedmann & Rahamim, 2007; in native English speakers see Kezilas et al., 2014 & Kohnen et al., 2012); attentional dyslexia, expressed as letter migration between neighboring words (Friedmann et al., 2010); letter identity dyslexia, expressed as difficulty in letter naming, or matching letters in divergent cases (Brunsdon et al., 2006); surface dyslexia, described as a difficulty of quick and accurate reading of known written words (Castles, 1996; Kohnen et al., 2018); and phonological dyslexia, described as a difficulty for reading unknown or nonwords (Castles & Coltheart, 1993; Coltheart, 1996; Temple & Marshall, 1983; for review of subtypes see, Friedmann & Coltheart, 2018). Despite this research, univariate approaches to dyslexia tend to focus primarily on phonological dyslexia and hence must find a way to explain the inherent variability within reading impaired samples.

We recognise and agree with the heterogeneous nature of reading impairment currently advocated for by the reading-research community. This paradigmatic shift is further elaborated by more recent proposals of multivariate models examining the causes of reading deficits (Catts et al., 2017; McGrath et al., 2020). However, this heterogeneity does not necessarily preclude the possibility of altered functioning in what has been defined as an anchoring mechanism, or, an impairment in some general capacity that reflects a risk factor for more specific deficits. Indeed, if studies included a broader array of reading-subskill tests, this would allow for a more focussed development of the anchoring deficit hypothesis (as well as other univariate approaches) with respect to subtypes of dyslexia. The issue is further complicated by the variable demographics of the included studies. Research examining the relationship between perceptual anchoring and developmental trajectory highlight that perceptual anchoring may change, not only as a function of age but also by acquired deficits (e.g., age-related-hearing loss, Banai & Yifat, 2011; Karawani et al., 2016; Manheim et al., 2018). Further, if we agree that reading impairment occurs across a continuum, then assessments should include a broader array of reading tests that help specify individual reading strengths and weaknesses and better describe the variability in our population samples. This, in turn, will allow for a more focussed development of the hypotheses aimed at detailing anchoring processes and how they may be implicated in various dyslexia subtypes.

# Conclusion

We report a narrative and quantitative synthesis of decreased performance in perceptual anchoring tasks for a sub-group of the dyslexia population relative to typical reading controls. Based on these findings, and current state of the literature, we hold that the anchoring deficit hypothesis remains a productive and valuable line of enquiry toward better understanding the heterogeneous nature of dyslexia and its causes. Future exploration, and subsequent replications, should strive for greater sensitivity in their experimental design and for methodological approaches that reflect the inherent variability in the dyslexia population.

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# Appendix

Appendix A:Search terms for literature search:

* Perceptual anchoring; perceptual learning; anchoring deficit; statistical learning
* Reading ability; poor reading; dyslexia; reading disability or difficulty or disorder or impairment or deficit or delay; learning disability or difficulty or disorder or impairment or deficit or delay.

Appendix B: Rationale for exclusions in step 5 of study selection:

1. Willburger, E., & Landerl, K. (2010). Anchoring the deficit of the anchor deficit: dyslexia or attention? Dyslexia, 16(2), 175-182.
   1. Measure of interest was contrast threshold for each condition (small/large stim set; without/with noise). Lower contrast threshold indicates participants detected the stimulus at lower contrasts. Higher contrast threshold indicates participant’s detected stimulus at higher contrast. Regardless of condition, the luminance of stimuli varied on a trial-by-trial basis (depending on staircase). There was no opportunity for a participant to anchor to particular stimulus and stimulus continually changed (no repeated condition). The results support noise exclusion impairments but do not adequately address prediction for/against anchoring deficits.
2. Beattie, R., Zhong-Lin, L., & Manis, F. (2011). Dyslexic Adults Can Learn from Repeated Stimulus Presentation but Have Difficulties in Excluding External Noise.
   1. Perceptual anchoring was established using time estimation task. Only a repeated condition was reported so, technically, there is no way to say if perceptual anchoring occurred.

## Appendix C:

|  |  |  |
| --- | --- | --- |
| **Category** | **Name** | **Description** |
| **Group Descriptors** |  |  |
|  | Criteria | Criteria used to define perceptual anchoring and reading ability |
|  | N | Sample size |
|  | Age/Grade | Age and/or grade of groups (central tendency, variation and range) |
|  | Sex | Number of females in group |
|  | IQ | Verbal and Nonverbal scores |
|  | Language | Dominant language/written language |
| **Perceptual Anchoring** |  |  |
|  | Classification | Typical/atypical parameters |
|  | Measure | Measures used |
|  | Statistics | Effect size (e.g., d’) |
| **Reading Ability** |  |  |
|  | Tests | Test/Assessments used |
|  | Impaired | Means (M), standard deviations (SD), and effect sizes (ES) on tests showing impaired reading |
|  | Spared | M, SD and ES on tests showing unimpaired reading. |
| **Theory** |  |  |
|  | Quotes | A list of quotes pertaining to the rationale, theoretical motivation, and hypotheses of the work. |

## Appendix D:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Risk of Bias: Experimental design** | | | | **Risk of Bias Rating** |
| **Selection (circle one rating per numbered item)** | **1) Representativeness of the sample:** | | a) truly representative of the average in the target population  (all subjects or random sampling) | 3 |
| b) Somewhat representative of the average in the target population | 2 |
| c) selected group of users | 1 |
| d) No description of the sampling strategy | 0 |
| **2) Sample size:** | | a) Justified (i.e., author explicitly states reasoning behind reported sample size) | 1 |
| b) Not justified | 0 |
| **3) Sample quality:** | | a) Researchers identify potential confounds and control appropriately | 3 |
| b) Researchers identify potential confounds and do not control appropriately | 2 |
| c) The study controlled for any additional factor (attention, age, sex, SES, neurological or medical problem) | 1 |
| **Risk of Bias: Perceptual Measures** | | | |  |
| **Outcome (circle one rating per lettered item)** | **1) Assessment of the outcome (if multiple outcomes, complete "assessment of outcome" for each outcome measure)** | | a) Measure(s) are described appropriately in context of research question. (i.e., not described, somewhat described, well described) | 0/1/2/3 |
| b) Researchers justify thresholds for perceptual ability (e.g., good listeners, bad listeners). | 0/1 |
| **2) Statistical test** | | a) Analysis of measure outcomes are reported accurately | 0/1 |
| b) Statistical tests are appropriate for research question (i.e., inappropriate, somewhat appropriate, appropriate) | 0/1/2 |
| **Risk of Bias: Reading Measures** | | | |  |
| **Outcome (circle one rating per lettered item)** | **1) Assessment of the outcome (if multiple outcomes, complete "assessment of outcome" for each outcome measure)** | | a) Measure(s) are described appropriately in context of research question. | 0/1/2/3 |
| b) Researchers justify thresholds for reading ability (e.g., good listeners, bad listeners). | 0/1 |
| **2) Statistical test** | | a) Analysis of measure outcomes are reported accurately | 0/1 |
| b) Statistical tests are appropriate for research question | 0/1/2 |
| **Total** | | | | /21 |
| **Incomplete outcome data** | |  | | |
| **Selective reporting** | |  | | |
| **Other bias** | |  | | |