Vision dominates audition in adults but not children: A meta-analysis of the Colavita effect

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Abstract

The Colavita effect occurs when participants respond only to the visual element of an audio-visual stimulus. This visual dominance effect is proposed to arise from asymmetric facilitation and inhibition between modalities. It has also been proposed that, unlike adults, children appear predisposed to auditory information. We provide the first quantitative synthesis of studies exploring the Colavita effect, converging data from 70 experiments across 14 studies. A mixed-meta-regression model was applied to assess whether the Colavita effect is influenced by methodological factors and age group tested. Studies reporting response time data were used to test for the presence of asymmetrical facilitation between modalities. Studies exploring the Colavita effect in adults yielded a medium, approaching large, effect size. Studies exploring the Colavita effect in children yielded a small, reverse, Colavita effect. Across adult and child studies, no methodological factors influenced the effect. Contrary to asymmetrical facilitation, response time data suggested a general slowing under bimodal conditions. These findings suggest that whilst vision dominates in adults, this effect is absent in childhood.

Key words:

Colavita Effect; Sensory Dominance; Visual dominance; Meta-analysis; Development

1. **Introduction**

Our world is perceived through multiple senses, but it is unclear whether information from all senses is treated equally. Whilst reading this paper, are you more likely to be distracted by the sight of an email pop-up on your screen, or the sound of your phone ringing? Furthermore if your phone rings and an email pops-up simultaneously, which do you respond to first? The answer to these questions may lie with sensory dominance.

Colavita (1974; 1976) reported that when participants were presented with an auditory and a visual stimulus simultaneously they responded as though only the visual stimulus had occurred, and frequently reported having not perceived the auditory stimulus at all. This *Colavita effect* was found even when the auditory stimulus (a tone) was presented at twice the subjective intensity of the visual stimulus (a light), ruling out a simple explanation of physical inequality between the two modalities (Colavita, 1974). A *Colavita error* is defined as occurring when participants respond only to the visual element of a bimodal, in this case audio-visual, target. This effect has been used to imply a hierarchy of sensory processing in which visual information is given precedence.

Multiple studies have since replicated the Colavita effect, although the extent of the effect does appear to depend on the specific instructions given to participants. Studies conducted in the decade following the original study used two response keys and instructed participants to “make a response appropriate to the signal recognised first” (Colavita, 1982; Colavita & Weisberg, 1979; Johnson & Shapiro, 1989; Shapiro, Egerman, & Klein, 1984). These studies found Colavita “errors” to occur on a relatively large number of bimodal trials ranging from 38-98%. However, it is possible that participants still perceived both visual and auditory signals, and made unimodal responses in accordance with instructions. More recent studies (Koppen & Spence, 2007a, 2007b, 2007c, 2007d) instructed participants to press both keys on bimodal trials. Although the number of visual-only responses was smaller in these studies (0.9-12.1%) these error rates remained significantly higher than auditory-only responses, thus supporting the presence of the Colavita effect.

In contrast, variations in other task manipulations do not appear to influence the Colavita effect. Qualitative reviews of literature exploring visual precedence in adults (Spence, 2009; Spence, Pairse, & Chen, 2012) have concluded the Colavita effect to be relatively insensitive to manipulations of stimulus intensity (Colavita, 1974; Shapiro & Johnson, 1987), attention bias to one or other modality created by the experiment (Egeth & Sager, 1977; Koppen & Spence, 2007a, 2007c; Sinnett, Spence, & Soto-Faraco, 2007), response demands (Egeth & Sager, 1977; Hecht & Reiner, 2009; Koppen & Spence, 2007c; Sinnett et al., 2007) and stimulus complexity (Koppen, Alsius, & Spence, 2008; Sinnett et al., 2007). This suggests that visual precedence may have an origin beyond simply response bias. However, since the previous review was descriptive, and over ten large studies have been published since, a quantitative update of the review is essential. Therefore, the primary aim of the current study was to quantify how robust the Colavita effect is, and, furthermore, whether it can be manipulated by task demands or age group tested.

The additional factor of age may be of particular importance to the sensory dominance literature. Robinson and Sloutsky (2004) suggested that visual dominance may develop across the lifespan and therefore that visual dominance is weaker in childhood. Indeed, the auditory system undergoes substantial development in utero (Graven & Browne, 2008a) whereas the visual cortex undergoes lengthy, protracted development throughout childhood (Graven & Browne, 2008b). Consequently, children may rely less upon visual input early in life. In line with this it has been shown that young children struggle to ignore auditory information when focusing upon visual stimuli (Hanauer & Brooks, 2003). Furthermore. it has been shown that children manifest a smaller, sometimes reverse, Colavita effect (Nava & Pavani, 2013; Wille & Ebersbach, 2016). Given this, a comparison of the Colavita effect across studies using different age groups is of great theoretical interest.

A further aim of the current study was to explore the mechanisms underpinning the Colavita effect. Sinnett et al. (2008) proposed that the appearance of visual precedence is due to an asymmetrical inhibitory-facilitatory relationship between vision and audition (Sinnett, Soto-Faraco, & Spence, 2008). Sinett et al., (2008) report that in simple detection tasks (using a single key) presenting auditory and visual stimuli together facilitated response times. Conversely, in discrimination tasks (using multiple keys) presenting auditory and visual stimuli together impeded response times. In a second experiment, they found that in a simple detection task, auditory stimuli facilitated response times to visual targets whilst visual stimuli impaired response times to auditory targets. These opposing effects have been used to infer an asymmetrical inhibitory-facilitatory relationship between audition and vision.

Sinnett et al. (2008) propose that this asymmetrical relationship might result in Colavita errors, as when participants are presented with bimodal targets the ‘internal threshold’ for responding to visual targets is reached sooner than auditory targets (Spence, 2009). Thus visual processing interferes with, and delays, auditory target detection and speeded responses are most likely to be visual-only responses (Spence, 2009). This hypothesis is supported by event-related potential (ERP) data, showing ERPs to audio-visual stimuli occur at an increased latency relative to auditory only ERPs and a decreased latency relative to visual only ERPs (Molholm et al., 2002).

Nevertheless, previous literature has supported symmetrical, facilitatory, relationships between vision and audition. Response times to bimodal targets in general are typically faster than unimodal targets when a single response key is used; the redundant target effect (Diederich & Colonius, 2004; Forster, Cavina-Pratesi, Aglioti, & Berlucchi, 2002; Gondan, Niederhaus, Rösler, & Röder, 2005; Sinnett et al., 2008). Furthermore, detection thresholds for luminance appear lower (Frassinetti, Bolognini, & Làdavas, 2002) and the saliency of visual events increases (Noesselt, Bergmann, Hake, Heinze, & Fendrich, 2008) with accompanying sound. Similarly, irrelevant visual stimuli can enhance auditory detection (Lovelace, Stein, & Wallace, 2003). Contrary to asymmetrical inhibition and facilitation between vision and audition, these findings suggest general multisensory facilitation.

A general, symmetrical, model of multisensory facilitation is consistent with theories of superadditivity, whereby neural responses elicited from bimodal targets are greater than the sum of responses to unimodal elements (Meredith & Stein, 1986; however see Holmes, 2009; Holmes & Spence, 2005 for discussion of interpretations regarding superadditivity). Interestingly, although visual and auditory evoked ERPs are asymmetrically influenced by one another with respect to latency, the amplitude of ERPs to audio-visual stimuli are greater than the sum of both unimodal auditory and unimodal visual responses (Molholm et al., 2002). It is unclear however how multisensory integration mechanisms may favourably decrease response times to visual but not auditory targets and whether physiological models can accommodate asymmetries in cross-modal influences.

Given the mixed literature regarding symmetrical versus asymmetrical inhibition and facilitation between vision and audition we aimed to test this within the existing Colavita literature. Furthermore, Sinnett and colleagues 2008 hypothesis is based upon findings from a simple detection task (using a single response key). In contrast to this many Colavita studies have utilised multiple response keys and Sinnett and colleagues note that with multiple response keys slowing can be observed. Given this we aimed to test whether asymmetrical response time effects are observed within the wider Colavita literature, in which multiple response keys were sometimes used.

The current paper aims to provide the first quantitative synthesis of literature exploring the Colavita effect. This paper reports a meta-analysis of both Colavita errors (making a unimodal visual response when bimodal stimuli are presented) and response time asymmetries. Given the specific predictions provided by Sinnett and colleagues with regards to auditory versus visual modalities, and the audio-visual nature of the Colavita effect in original reports (Colavita, 1974), we chose to focus on studies comparing auditory versus visual modalities. Nevertheless it should be noted that the Colavita effect has since been extended to the visual-tactile domain (for details see, Hartcher-O'Brien, Levitan, & Spence, 2010; Hecht & Reiner, 2009). By including data from multiple studies we can overcome some of the limitations of individual studies. Small sample sizes have been used in many cases and effect sizes vary. For instance, Colavita's early (1974; 1976; 1979) experiments contained very few participants (n=10) and trials (35 trials per participant, 5 bimodal).

To allow comparison between the present quantitative review and the qualitative review by Spence (2009) we included variables highlighted by Spence (2009) as potential moderator variables. Specifically, we predicted that the Colavita effect would be insensitive to manipulations of:

- Number of response keys (2 or 3). Note that studies including only a single response key were considered for the response time analysis only, as Colavita errors cannot be made with a single response key.

- Ratio of visual, auditory and bimodal targets (and in one case no target present).
- Attentional manipulation: i.e. was attention biased towards the visual or auditory modality either through arousal, cueing, perceptual biasing (if the light was twice the subjective intensity of the sound), or via instructional manipulation (participants asked to attend to or respond only to auditory information).
- Stimulus category: simple (i.e. tones and lights) vs. complex (i.e. pictures/videos and natural sounds)
- Whether auditory and visual stimuli were perceptually matched in intensity (either subjectively or based upon thresholds).
- Stimulus congruency: A stimulus could be “congruent” semantically, picture of a cat and the sound of a cat, or spatially, a visual stimulus on the left and a sound on the left

Furthermore, we extend the comparisons to include:

- Age Group (child vs. adult). We predicted a reduced Colavita effect in children.
- Asymmetric facilitation and inhibition. We included studies using Colavita tasks that also reported response times to test the prediction of Sinnett et al (2008); that response times to visual stimuli are faster under bimodal conditions, whilst response times to auditory stimuli are slower under bimodal conditions.

2 Method

2.1 Search and inclusion criteria

Studies were retrieved and selected using the guidelines outlined in PRISMA (Moher D, Liberati A, 2009). Figure 1 outlines the search strategy used. Studies were found by searching the electronic databases Scopus, PubMed and Web of Science (July 2016- August 2017) and reviewing the references of studies sourced. Initial search terms included: *Colavita effect* (64 hits across all data-bases), *Colavita* (362 hits across all data-bases) and *sensory dominance* (256 hits across all data-bases). The following inclusion criteria were then applied:

- Studies using a choice response time task to compare responses to unimodal and bimodal stimuli in humans (figure 1. Box b).
- Studies comparing responses to auditory, visual and audio-visual targets (figure 1 box c).
- Studies available to the author in English (figure 1 box c).
- Sources in which full text could be sourced (i.e. meeting abstracts and posters excluded) (figure 1 box c).
- Studies where error data and/or response time data for bimodal (audio-visual) stimuli could be sourced (either within the paper or via personal communication with the author- figure 1 box d). Notably, because response time analyses were performed to examine the effect of vision on audition and vice versa, response time data needed to be available for unimodal visual targets, unimodal auditory targets, visual targets in the presence of an auditory stimulus and/or auditory targets in the presence of a visual stimulus. Thus, response times for bimodal targets were not used for analyses, unless participants were asked to make separate responses for visual and auditory elements of the target (i.e. press both keys).

- Studies conducted upon healthy participants (children and adults). For example in two cases data was sought from the healthy control group of larger studies (Moro & Steeves, 2012, 2013).

[INSERT FIGURE 1 HERE]

Many of the studies sourced included multiple experiments, each containing its own conditions/comparisons. For example, Wille and Ebersbach (2016) conducted three experiments each containing three age groups, in which three levels of congruency were explored – thus providing 27 experiments for the purposes of our analysis. By breaking down each study into its component experiments a total of 121 experiments were available for analysis. Details of these studies can be found in Table 1.

Of the studies and experiments available, only those that provided sufficient information for the calculation of effect size data were included to explore the following dependant variables:

1. The overall Colavita effect as defined in Equation 1 where Vb refers to the percentage of visual-only responses made on bimodal trials and Ab refers to percentage auditory-only responses made on bimodal trials (14 studies, 70 experiments).

Equation 1

$$Colavita\ effect = \frac{Vb}{Ab}$$

2. Response times to unimodal visual targets vs. visual targets paired with an auditory stimulus (11 studies, 27 experiments).

3. Response times to unimodal auditory targets vs. auditory targets paired with a visual stimulus (10 studies, 24 experiments).

[INSERT TABLE 1 HERE]

2.2 Statistical Analyses

Effect sizes were calculated for the percentage visual-only vs. auditory-only errors on bimodal trials (Colavita and reverse Colavita effects) as well as response times under unimodal visual vs. bimodal visual and unimodal auditory vs. bimodal auditory conditions.

Calculation of weighted effect sizes (see below) and model fitting was conducted using the metafor package in R[2] (Viechtbauer, 2010). Cohens guidelines of 0.2, 0.5, and 0.8 were used to define small, medium and large effect sizes respectively. Given the wide range of contexts under which the Colavita effect has been explored a *random effects* rather than a *fixed effects* meta-regression model was applied (Thompson & Higgins, 2002). Furthermore, the majority of studies included reported a range of differences in experimental procedure. As such these factors were held as moderator variables in order to explore the extent to which these factors could account for the variance of effect size between studies.

2. 2.1 Outliers

In line with the guidelines outlined by Cook and Weisberg, (1984) and Viechtbauer and Cheung, (2010), outliers and influential cases were identified and examined if:

[2] Full script and data will be available via open science framework upon publication https://osf.io/d7b3d/.

a) The absolute DFFITS value was larger than $3\sqrt{p/(k-p)}$ where p is the number of model coefficients and k the number of studies, suggesting the average effect size to be influenced by inclusion of ith study.

b) Cooks distance exceeded ${X^2}_{p,0.5}$, indicating the mahalanobis distance between studies to be decreased following the deletion of *i*th study.

c) The study was shown to have considerable leverage upon the fit of the model based upon a hat value larger than $3(p\ /\ k)$.

For further information on these parameters see Viechtbauer & Cheung (2010). Combined effect sizes are shown including and excluding influential studies. These studies were not included within the modelling of moderator variables.

2. 2.2 Calculation of effect sizes

Measures of effect size were calculated using Cohens d_{av}, where the average standard deviation of both sets of observations (S_{av}) is used as a standardizer (Lakens, 2013; Equation 2).

Equation 2

$$Cohen's\ d_{av} = \frac{M_{diff}}{\sqrt{\left(\frac{SD_1+SD_2}{2}\right)}}$$

We acknowledge that this is not the optimal measure of effect size for studying within-subject phenomenon. Alternative effect size measures, such as Cohens d_{rm} (see Lakens, 2013) take into account the correlation (*r*) between measures. However, although *r* is typically reported for clinical pre-post test designs, *r* is not always reported in experimental designs where trials are intermixed and correlation is not of primary interest (Dunlap, Jose, Vaslow, & Burke, 1996). Thus, unless raw data can be obtained, *r* is not always available. Few solutions to this problem have been suggested. Borenstein et al., (2009) suggested estimating the correlation based upon related studies and performing sensitivity analyses with a range of plausible correlations. Alternatively, r can be estimated from available t and f statistics (Hullett & Levine, 2003). However if these exact statistics are also unavailable one may need to estimate effect size directly from the means and standard deviations (Dunlap et al., 1996). Cohens d_{av} provides a convenient solution to this problem.

A further issue occurs however when calculating the variance around Cohens d_{av}. Cumming (2012) proposes Algina & Keselman's, (2003) approximate method for the calculation of confidence intervals (Equation 3), and subsequently variance (Equation 4), for Cohens d_{av} . This method still requires knowledge of r.

Equation 3

$$Cohen's\ d_{av_{CI}} = d_{av} \pm t_{(1-\frac{\alpha}{2}, n-1)} \sqrt{\frac{(2(SD_1^2 + SD_2^2 - 2r)}{n(SD_1^2 + SD_2^2)}}$$

Note: notation used by Algina and Keselman (2003) changed to be in line with current notation.

Equation 4

$$Vd_{av} = (\frac{CIup - CIlow}{2*1.96})^2$$

Thus if the researcher is unable to derive r from the available information similar problems are faced when calculating the variance of Cohens d_{av}.

To resolve this problem we utilised a method adapted from the calculation of variance for Cohens d for independent samples (Equation 5) where n_1 and n_2 signify the number of observations contributing towards M_{diff}.

Equation 5

$$Vd_{av} = \left(\frac{n_1 + n_2}{n_1 n_2}\right) + (\frac{d_{av}^2}{2(n_1 + n_2)})$$

Note this is a conservative method yielding marginally wider confidence intervals, relative to Algina & Keselman's (2003) approximate method (Equation 3 and 4), and thus assuming slightly greater variance. Where possible, we also calculated Vd_{av} using Equation 4 to estimate the true extent of the effect. For experiments studying the Colavita effect only 26 of the 70 experiments to be included contained sufficient information for calculation of r. In all of these cases our method proved to be more conservative; the mean variance was 0.114 (SD=0.05) when calculated using Equation 5 vs. 0.073 (SD=0.03) when calculated using the approximate method outlined in Equation 4 with knowledge of r .

Whilst $Cohen's\ d_{av}$ is the most appropriate method for sample estimates, it may be positively biased for population estimates. For this reason a corrected $Cohen's\ d_{av}$, Hedges g_{av} was calculated using Equation 6. Whilst the differences between d_{av} and g_{av} are very small, g_{av} provides an unbiased estimate of effect size (see (Cumming, 2012).

Equation 6

$$Hedges\ g_{av} = d_{av} * \left(\frac{3}{4 * n - 1} - 1\right)$$

To summarise, Hedges g_{av} (Equation 6) was used as the effect size measure within our analysis. The variance of g_{av} was calculated using Equation 5, in which d_{av} was substituted with g_{av}.[3]

2.2.3 Moderator variables

Given the range of contexts in which the Colavita effect has been explored the studies included in our meta-analyses were heterogeneous in terms of the methods used. As such we aimed to explore the following 8 factors by including them as moderator variables within a mixed-effects model of the data:

- Number of response keys (1,2 or 3)
- Ratio of visual, auditory and bimodal targets (and in one case no target present).
- Age Group (child vs. adult)
- Stimulus category (simple (i.e. tones and lights) vs. complex (i.e. pictures/videos and natural sounds))
- Whether auditory and visual stimuli were perceptually matched in intensity (either subjectively or based upon thresholds).
- Stimulus congruency (i.e. A stimulus could be "congruent" semantically, picture of a cat and the sound of a cat, or spatially, a visual stimulus on the left and a sound on the left. Likewise stimuli could be "incongruent" semantically, a picture of a cat and sound of a dog, or spatially, visual stimulus on the left auditory stimulus on the right.)
- Attentional Manipulation (i.e. was attention biased towards the visual or auditory modality either through arousal, cueing, perceptual biasing (i.e. if the light was twice the subjective intensity of the sound) or via instructional

[3] Spreadsheet allowing replication of effect size calculation will be available via open science framework upon publication https://osf.io/d7b3d/.

manipulation (i.e. participants asked to attend to or respond only to auditory information)).

3 Results

3.1 Error data analyses: The Colavita effect

Figure 2 illustrates the effect size of the Colavita effect in each experiment within each study. Positive effect sizes indicate more “visual only” responses on bimodal trials. Conversely experiments with negative effect sizes found more “auditory only” responses on bimodal trials. The combined effect size estimate reached Cohen’s standard for a small effect size, 0.44 (SE=0.1), but was significant (p<.001). This suggests that participants made more visual-only responses under bimodal stimulus presentation than auditory-only responses. One experiment (Monem & Filmore 2016 experiment 1.2.1) was identified as an influential case. Removal of this experiment decreased the overall effect size to 0.4 (SE=0.09), however this was still significant (p<.001).

To explore the effects of moderator variables a mixed meta-regression model was conducted in which the intercept was set to reflect the effect size of studies using the most frequently used experimental parameters (adult participants, simple stimuli that were neutral in congruency and attentional manipulation, a trial ratio of 40(visual):40(auditory):20(bimodal), 2 response keys). All studies included in this analysis presented stimuli at fixed intensities.

The estimated amount of residual heterogeneity in this meta-regression model (tau^2=0.24, SE=0.06), suggested that the included moderator variables accounted for 41.84% of the variability. This was significant based upon an omnibus test (QM(df=12)=46.17, p<.001). The intercept significantly differed from 0 (p<.001) with a medium, approaching large, effect size estimate of 0.79 (SE=0.15). Only one factor, age group, significantly influenced this effect size estimate (p<.001) suggesting that experiments with child participants (aged 6-12 years) decreased this effect size by 0.89 (SE=0.18). Six separate ANOVAs were then conducted to clarify the effect of each factor upon the intercept. These ANOVAs supported the mixed model indicating that only age group influenced the effect size of the Colavita effect (see Table 2). It should be noted however that a test for residual heterogeneity was also significant (QE(df=56)=211.63, p<.001), suggesting other factors not accounted for in this model are also likely to be important.

[INSERT TABLE 2 HERE]

3.1.1 Effect of age group

A further model was fitted to directly compare the effect sizes of studies using adult and child participants (regardless of other factors). For details of studies included in this comparison see Table 1 column 4 labelled Age Group. Studies included were those with children as participants. Unlike the model described above, here we included studies using all types of ratio and stimuli (rather than only "typical" parameters). This model indicated that the effect size significantly differed from zero in adults (M = 0.76 , SE=0.09; p < .001) but not children (-0.26, SE=0.13; ns). Experiments investigating the Colvita effect in adults yielded a medium, approaching large, effect size whilst studies including children (aged 6-12 years) yielded an effect that was significantly smaller (p<.001) than that of adults, but did not significantly differ from 0. Thus, although children appeared to show a small reverse Colavita effect this did not reach significance.

[INSERT FIGURE 2 HERE]

3.1.1.1 Publication bias

To evaluate the presence of publication bias, data from studies included in model 1 (analysing the Colavita effect) were plotted as a funnel plot (Figure 3). The amount of scatter around the true effect should decrease with decreased sampling variance/increased sample size, thus producing a classic "funnel" shape (Macaskill, Walter, & Irwig, 2001). Publication bias is associated with funnel plot asymmetry (Egger, Davey Smith, Schneider, & Minder, 1997), whereby studies with large sampling variance/smaller sample size scatter to the left or right of the true effect. To quantify asymmetry we conducted a meta-analytic mixed effects regression analysis, holding sample size of studies as a predictor variable. This test indicated no significant asymmetry ($z=1.03$, $p=0.3$, Figure 3), suggesting the reported findings were not influenced by publication bias.

[INSERT FIGURE 3 HERE]

3.2 Asymmetrical Facilitation: Response Time analyses:

We used studies that had reported response times to auditory and visual stimuli under unimodal and bimodal conditions to investigate whether the Colavita effect occurs due to asymmetrical facilitation and inhibition (Sinnett et al., 2008). Our first analysis compared whether response times were faster to a visual stimulus presented with an auditory stimulus (i.e. bimodal) vs. unimodal visual targets (i.e. do auditory stimuli facilitate response times to visual targets?). Our second analysis examined whether response times were slower to an auditory stimulus presented with a visual stimulus (i.e. bimodal) vs. unimodal auditory targets (i.e. do visual stimuli impede response times to visual targets?). Across both sets of analyses positive effect size values would indicate response times were faster to the target under bimodal conditions. Conversely, negative effect sizes would indicate response times were faster to the target in unimodal conditions.

3.2.1 Do auditory stimuli facilitate response times to visual targets?

The combined effect size resulting from comparing response times to visual stimuli under unimodal vs. bimodal conditions was -0.24 (SE=0.18) and non-significant (Figure 4). Two experiments (Egeth and Sagar (1977) experiment 4.2 and Koppen and Spence (2007b) experiment 2.1) were identified as influential outliers. Removal of these studies resulted in an effect size of -0.42 (SE=0.13) which was significantly different from 0 (p<.001). Contrary to Sinnett and colleague's (2008) predictions of asymmetrical facilitation, response times were in fact *slower* for visual stimuli when they were accompanied by auditory stimuli compared to when they were presented alone.

To explore the effects of moderator variables a mixed meta-regression model was conducted in which the intercept (reference) was set to reflect the effect size of studies using the most frequently used experimental parameters, as above. This model indicated that 96.15% of the residual heterogeneity (tau^2=0.01, SE=0.04) was accounted for by the inclusion of moderator variables (QM(df=12)=74.02, p<.001). The effect size estimate of the intercept was large (-1.0073, SE=0.1308), and decreased in studies using ratios in which bimodal stimuli were more frequent (20:20:60, 25:25:50 and 33:33:33; yielding estimated changes of 1.73 (SE=0.38, p<.001), 1.18 (SE=0.44, p<0.01) and 0.42 (SE=0.18, p=0.02) respectively). Thus, when bimodal trials were infrequent (20%) response times were slower to visual targets under bimodal conditions. However when bimodal targets were more frequent (33%, 50% or 60%) this effect was decreased The effect size was also decreased by 1.58 (SE=0.36, p<.001) in studies using complex stimuli and increased by 1.34 (SE=0.55, p=.02) in experiments using congruent stimuli. In line with this, post-hoc ANOVAS showed a significant overall effect of ratio, stimulus category, and congruency upon the intercept whilst other factors did not yield a significant overall effect (table 3). A test of residual heterogeneity was non-significant (QE(df=11)=11.95, p=0.37) suggesting there was no further heterogeneity not accounted for within the model.

[INSERT TABLE 3 HERE]

Given the significant effect of ratio (i.e. the balance of audio-visual, unimodal visual and unimodal auditory trials) and stimulus category (i.e. simple such as flashes and tones versus complex such as images and naturalistic sounds) found above, two further models were fitted to directly compare the effect size of multisensory facilitation/interference of studies using different ratios and stimulus categories regardless of other factors. A further model was not fitted to explore the effect of congruency as this had only been manipulated in one study.

The model for ratio indicated that only studies using the ratios 40:40:20 yielded effect sizes that significantly differed from 0 (p<.001). This suggested that when bimodal trials were infrequent (20%) response times to visual stimuli were slower under bimodal conditions. However when bimodal trials were more frequent (33%, 50% or 60%) response times were not significantly affected by auditory stimuli.

The model addressing stimulus category (simple vs complex), revealed that only experiments using simple stimuli yielded an effect size that significantly differed from 0 (p<.001). This suggested that participants were slower to respond to visual stimuli paired with auditory stimuli but only when simple stimuli were used.

Overall these findings were not consistent with our hypothesis that response times to visual targets would be faster under bimodal vs. unimodal conditions. Rather, these findings suggested response times were slower to visual targets paired with auditory stimuli particularly when the frequency of bimodal targets was low and when simple stimuli were used.

[INSERT FIGURE 4 HERE]

3.2.2 Do visual stimuli impede response times to auditory targets?

The combined effect size for unimodal auditory vs. bimodal auditory RTs was medium, (-0.55, SE=0.08), and significant (p<.001). One experiment, Yue et al (2015) experiment 1.2, was judged as influential outlier. Removal of this study decreased this effect size to -0.50 (SE=0.07). However this still significantly differed from zero (p<.001).

A mixed meta-regression model was fitted for this effect in which studies using the parameters outlined as standard (see above) were used as the intercept. This model revealed no significant remaining heterogeneity (tau^2=0, SE=0.04, QE(df=13)=4.37, p=.9867) and a non-significant effect of moderators (QM(df=9)=14.74, p=0.1). From this we conclude that participants were slower for auditory targets paired with visual stimuli compared with unimodal targets, as can be seen in Figure 5, and this was not modulated by experimental parameters.

[INSERT FIGURE 5 HERE]

3.2.3 Is the bimodal slowing effect between vision and audition symmetrical?

Contrary to our predictions based on the model of Sinnett et al., (2008) we found that vision slowed response times to auditory targets and vice versa. Robinson, Chandra, & Sinnett (2016) noted that this might when multiple response keys are used, and conceptualised sensory dominance via the relative extent to which one sense slows another. They found that, when a single response key was used, visual stimuli slowed auditory response times more than auditory stimuli slowed visual response times. Moreover, when separate response options were available, auditory stimuli *also* slowed response times to visual stimuli. The authors interpret the extent to which one sense slowed the other as a measure of sensory dominance. To test whether vision slowed response times to auditory targets more than vice versa, a final model was fitted to directly compare the effect sizes yielded in our former two comparisons. No significant difference was found, suggesting visual and auditory stimuli slowed response times to the opposing modality to a similar extent.

4. Discussion

The current study quantitatively demonstrates that Colavita errors, whereby participants report only the visual element of an audio-visual target, are a robust experimental phenomenon. Mixed-effects analyses also corroborated the suggestion that Colavita errors are relatively insensitive to response demands, attentional manipulation, stimulus ratio, stimulus complexity, and congruency. However, residual heterogeneity did remain within the model therefore it should be noted that other factors not accounted for in our model are likely to influence the effect size of the Colavita effect.

Furthermore, we show that the Colavita effect may be modulated by age, in that it is smaller, even reversed, in childhood. Although the current analysis includes only 2 childhood studies, these studies include data from a relatively large sample of 187 children aged between 6 and 12 years (Nava & Pavani, 2013 n=51; Wille & Ebersbach, 2016 n=136). This is in line with evidence suggesting an auditory preference in childhood (Napolitano & Sloutsky, 2004; Robinson et al., 2016; Robinson & Sloutsky, 2004, 2010; Sloutsky & Napolitano, 2003) and difficulty ignoring auditory distractions in childhood (Hanauer & Brooks, 2003). These previous findings together with the current data make an interesting case for the fluctuation of sensory dominance across the lifespan and highlight this as a field warranting further investigation.

Our response time analysis suggest that response times were slower for both visual and auditory stimuli when responded to under bimodal vs. unimodal conditions. Furthermore the effects of vision on audition and vice versa were not significantly different. The current study therefore does not suggest an asymmetrical relationship between vision and audition as proposed by Sinnett et al (2008). They hypothesised a co-occurrence of multisensory facilitation and inhibition whereby auditory stimuli facilitate visual detection, whilst visual stimuli inhibit auditory detection. This asymmetry was proposed to result in the Colavita effect as a visual response would be more likely to occur first on bimodal trials. An alternative, symmetrical, prediction is that response times are always faster under bimodal conditions. This would be expected based upon the known principles of multisensory integration, whereby neural responses elicited from bimodal targets are greater than the sum of responses to unimodal elements. This is known as superadditivity (Meredith & Stein, 1986). However, our findings indicated that response times were in fact *slower* under bimodal conditions. This finding appears contrary to both asymmetric and symmetric models of multisensory facilitation.

One possible explanation for this is that studies of the Colavita effect use at least two response keys, whereas previous literature finding multisensory facilitation (faster responses on bimodal trials) has used simple response time tasks with one response key (Forster et al., 2002; Gondan et al., 2005; Sinnett et al., 2008). Moreover, most Colavita studies traditionally present response time data for correct trials. If multisensory facilitation does contribute to the Colavita errors however, the beneficial effects of audition upon visual response times might be more evident within incorrect trials. For example, in order to respond to a bimodal target correctly (i.e. with both buttons) it would be expected that participants must first suppress the automatic tendency to respond towards only the visual target and then make the correct, bimodal, response. Thus, response times on correct trials would be slower due to the need to suppress automatic responses.

Surprisingly, our response time analysis indicated that auditory stimuli slowed response times to visual targets, suggesting that this effect was decreased in studies using fewer bimodal trials. This contradicts previous findings by Sinnett et al., (2007, experiment 3), who found that the frequency of bimodal targets did not influence reaction times. It is possible that a more equal distribution of unimodal and bimodal target types (33% visual, 33% auditory and 33% audio-visual) produces equivalent response times across targets by limiting effects such as novelty. Thus, although the influence of stimulus ratio on response times was not revealed at the single study level, combining across several studies did yield this effect.

Notably only one study in adults yielded a clear reverse Colavita effect (Ngo, Cadieux, Sinnett, Soto-Faraco, & Spence, 2011). This study utilised a repetition detection variant of the Colavita paradigm. Participants were required to detect (n-1) repetitions in auditory, visual and audio-visual information. Based upon the modality appropriateness hypothesis (Welch & Warren, 1980) the temporal demands of this task were predicted to introduce auditory dominance. Ngo and colleagues also predicted that this would be exaggerated by the longer lasting nature of echoic vs. iconic short-term memory. The reversal of the Colavita effect in this study is therefore attributed to arise from a greater visual masking of targets by intervening irrelevant items under visual vs. auditory conditions. In line with this, if the intervening item was semantically meaningless (a pattern mask/ burst of white noise), neither auditory nor visual dominance was observed.

5. Conclusions

The current study provides an updated synthesis of literature surrounding the Colavita effect. The Colavita effect appears to be a robust phenomenon with medium effect size in adults. The Colavita effect also appears insensitive to many experimental manipulations although may be reversed under some designs (Ngo et al., 2011). This study highlights a need to examine the Colavita effect across the lifespan and suggests that visual dominance over audition may be weaker, or even reversed, in childhood.

Following this, and in answer to our original postulation, if you are an adult reading this paper you may be more distracted by an email pop-up versus your phone ringing. Furthermore, if your phone rings at the same time you see an email pop-up you may not answer the phone at all. For this, you can blame sensory dominance.

Ethical conduct

The methodology included here were approved by the University of Nottingham's ethical review board and conducted in accordance with the declaration of Helsinki.

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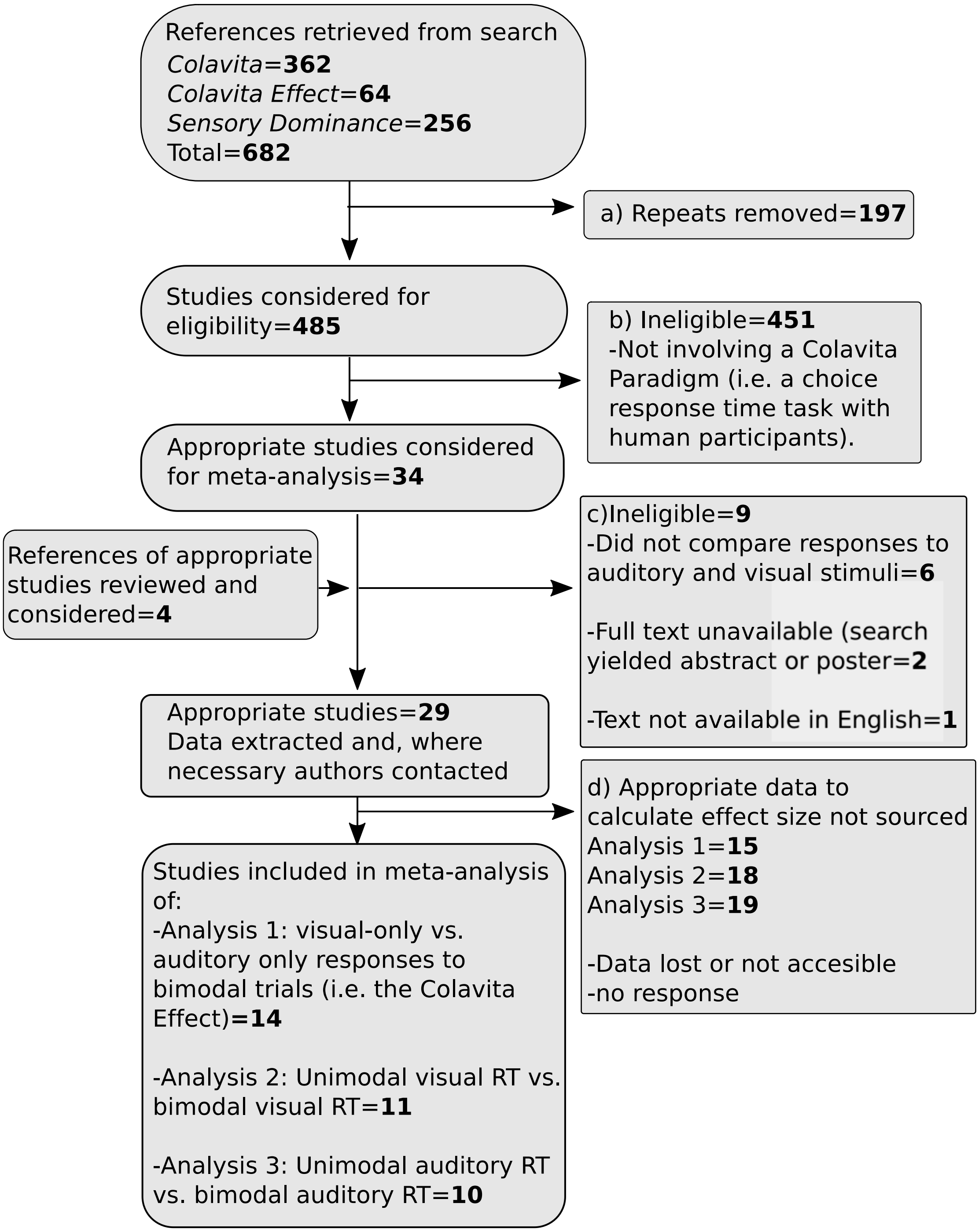

Figure 1. Flow diagram illustrating search strategy and exclusion criteria used to isolate studies to be included in the meta-analysis.

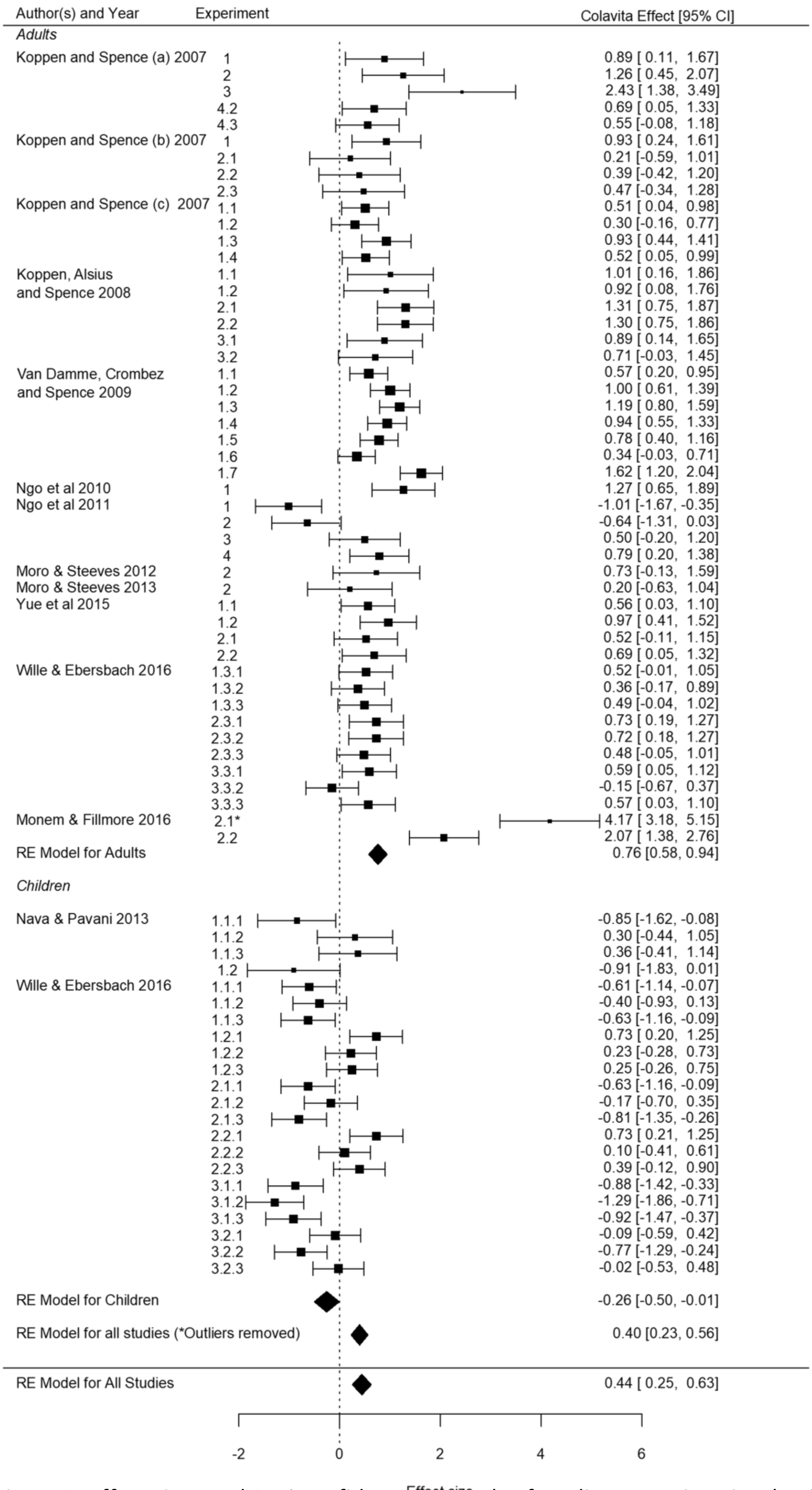

Figure 2. Effect sizes and 95% confidence intervals of studies reporting visual only responses on bimodal trials (the Colavita effect) and auditory only responses on bimodal trials. Weighted effect sizes are shown for all studies, all studies excluding outliers (asterisked experiments) and studies examining children and adults separately. Positive effect sizes indicate more "visual only" responses on bimodal trials. Negative effect sizes indicate more "auditory only" responses on bimodal trials.

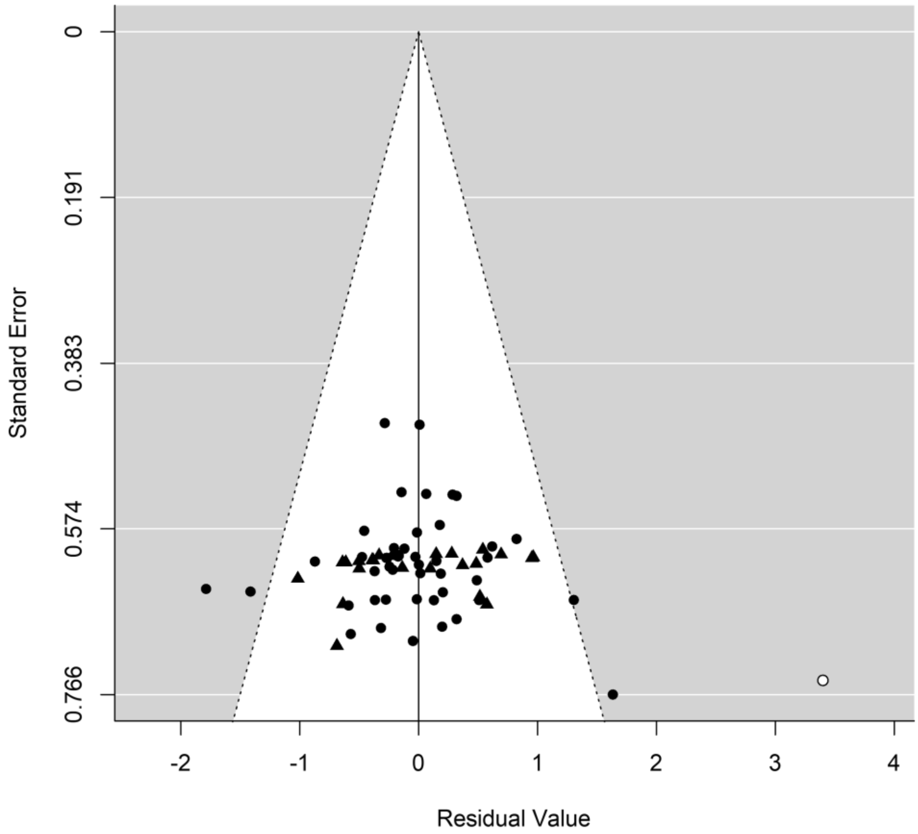

Figure 3. Funnel plot signifying the symmetrical distribution of effect size residuals (relative to the effect size of all studies) against standard error for studies reporting the Colavita effect. Circles = adult studies, Triangles = child studies, white circle = outlier/influential case

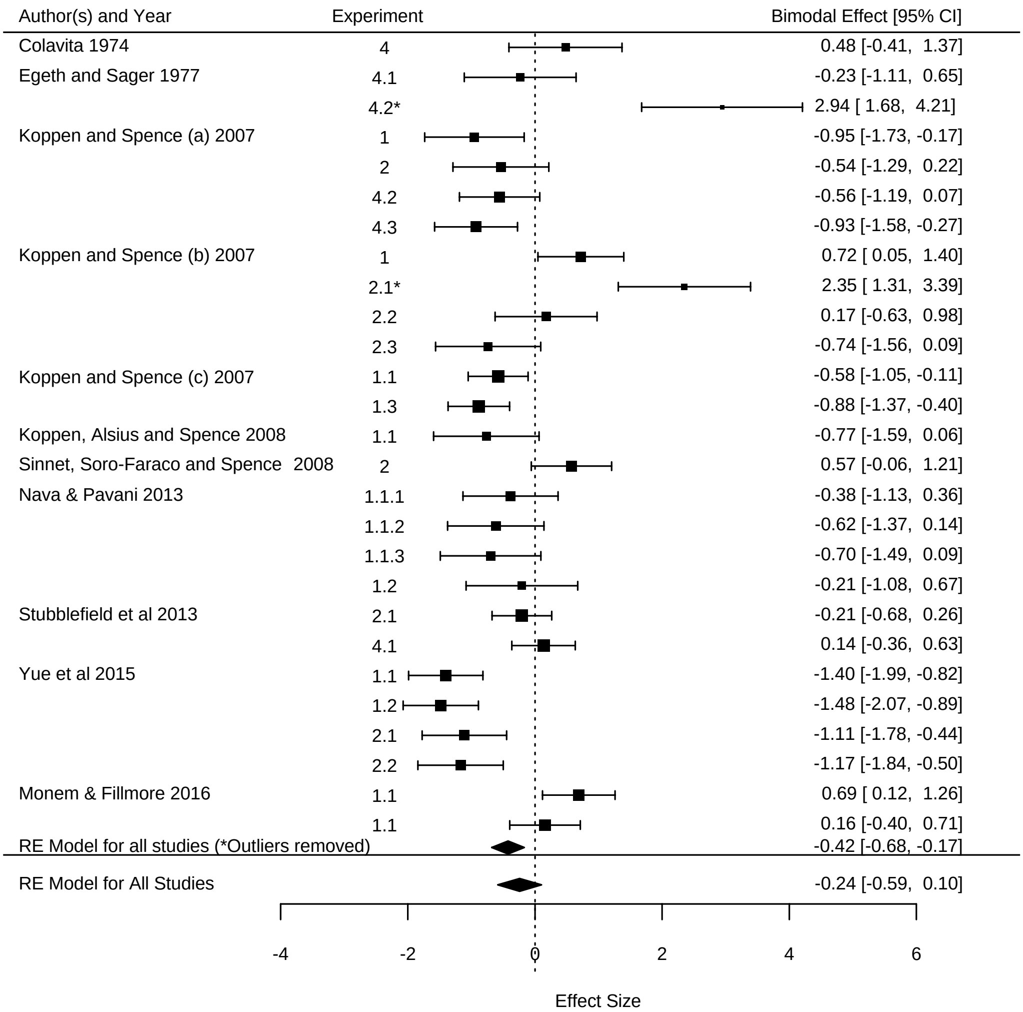

Figure 4. Effect sizes and 95% confidence intervals for studies/experiments reporting response times (RT) for visual targets under unimodal and bimodal conditions. Positive effect sizes indicate RT was faster under bimodal versus unimodal conditions. Negative effect sizes indicate RT was faster under unimodal versus bimodal conditions.

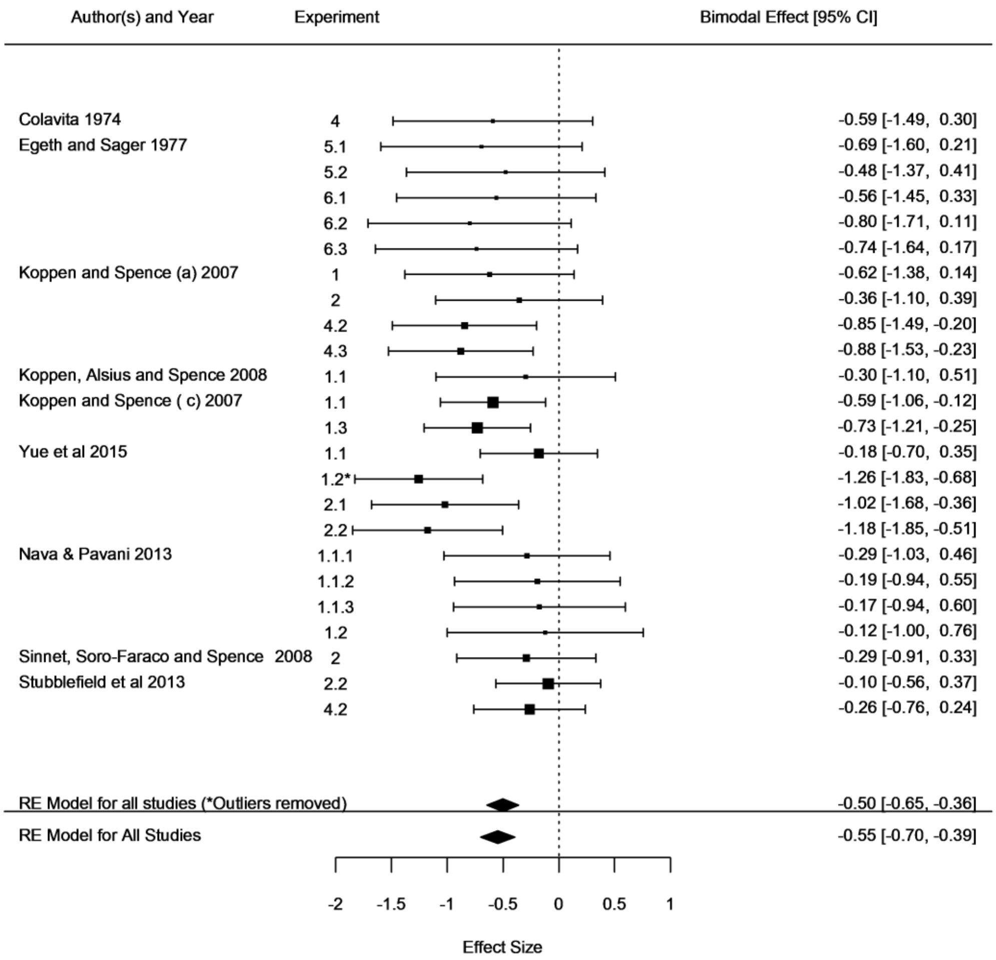

Figure 5. Effect sizes and 95% confidence intervals for studies/experiments reporting response times (RT) for auditory targets under unimodal and bimodal conditions. Positive effect sizes indicate RT was faster under bimodal versus unimodal conditions. Negative effect sizes indicate RT was faster under unimodal versus bimodal conditions.

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
Osborn, Sheldon, & Baker, 1963	1	41	Adult	20.2	simple	N	33:33:33	2	Press both buttons	-	-	✖	✖	✖
Colavita, 1974	1	10	Adult	-	simple	Y	43:43:14	2	No specific instructions	-	-	✖	✖	✖
	2	22				N				A (tone twice subjective intensity of		✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
										light)				
	3	10				Y			Press whichever key is appropriate to the signal you recognise first	-		✖	✖	✖

Author	Exp.	n	Age: Group	Age: M	Stimuli: Type	Stimuli: Matched	Stimuli: Ratio	Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for: Colavita	Unimodal vs. Bimodal RT: Visual	Unimodal vs. Bimodal RT: Auditory
	4	10				Y			Press the tone key	A (respond with tone key)		✗	✓	✓
Colavita, Tomko, & Weisberg, 1976	1	10	Adult	-	simple	N	43:43:14	2	Press whichever key appropriate for the signal recognised first	-	-	✗	✗	✗
	2	10								A (fixation moved away from light		✗	✗	✗

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
										source)				
Colavita & Weisberg, 1979	1	10	Adult	-	simple	Y	38:38:23	2	Press the tone key when the tone terminates and the light key if the light terminates	-	-	✖	✔	✔

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
Egeth & Sager, 1977	1	10	Adult	-	simple	Y	43:43:14	2	Press both keys	-	-	✖	✖	✖
	2	16					43:43:14	1	Press the tone key whenever you hear a tone	A (respond with tone key)		✖	✖	✖
	3.1	10					20:40:40	1		A (respond with tone key, and more		✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
										auditory targets)				
	3.2	10					20:40:40	2	Respond only to the tone	A (respond with tone key, and more auditory targets)		✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
	3.3	10					40:40:20	1	Press the tone key whenever you hear a tone	A (respond with tone key)		✖	✖	✖
	3.4	10					40:40:20	2	Respond only to the tone	A (respond with tone key)		✖	✖	✖
		10					40:40:20	2	Press the light	V (respond		✖	✔	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
	4.1								key	with light key)				
	4.2	10					20:40:40	2				✖	✔	✖
	5.1	10					40:40:20	2	Press the tone key	A (respond with tone key)		✖	✖	✔
	5.2	10					40:40:20	2		A (instructed		✖	✖	✔

Author	Exp.	n	Age: Group	Age: M	Stimuli: Type	Stimuli: Matched	Stimuli: Ratio	Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for: Colavita	Possible to calculate effect sizes for: Unimodal vs. Bimodal RT: Visual	Possible to calculate effect sizes for: Unimodal vs. Bimodal RT: Auditory
										to attend to auditory info)				
	6.1	12					40:40:20	2		A (respond with tone key)		✖	✖	✔
	6.2					N (light half subjectiv	40:40:20	2		A (light half intensity of		✖	✖	✔

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
						e intensity)				tone)				
	6.3					N (light twice subjective	40:40:20	2		V (light twice intensity of tone)		✖	✖	✔

Author	Exp.	n	Age: Group	Age: M	Stimuli: Type	Stimuli: Matched	Stimuli: Ratio	Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for: Colavita	Possible to calculate effect sizes for: Unimodal vs. Bimodal RT: Visual	Possible to calculate effect sizes for: Unimodal vs. Bimodal RT: Auditory
						intensity)								
Colavita, 1982	1	10	Adult		simple	Y	39:39:22	2	Press whichever key is appropriate to the signal you recognise first	-	-	✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matche d	Ratio						Visual	Auditory
Shapiro, Egerman & Klein, 1984	1.1	16	Adult	-	simple	N	40:40:20	2	Respond to the stimulus first perceived- informed that shock would occur if too fast or slow.	-	-	✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
	1.2	16							Respond to the stimulus first perceived			✖	✖	✖
	2.1	16					45:45:10		Respond to the stimulus first perceived- informed that			✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
									shock would occur if too fast or slow.					
	2.2	16							Respond to the stimulus first perceived			✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
	3.1	16							Respond to the stimulus first perceived- informed that shock would occur if too fast or slow.			✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
									Participants also received additional tactile stimulus with shock.					
	3.2	16							Respond to the stimulus first			✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
									perceived					
Johnson & Shapiro, 1989	1.1	12	Adult	-	simple	N	40:40:20	2	Respond to the stimulus you detect first- Visual stimulus appeared in random	-	-	✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
									location.					
	1.2	10							Respond to the stimulus you detect first- Visual stimulus appeared in same location			✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
									on all trials.					
	1.3	12							Respond to the stimulus you detect first- Subjects received random,			✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
									infrequent shocks following trials. Visual stimulus appeared in random location.					

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
	1.4	10							Respond to the stimulus you detect first-subjects received random, infrequent			✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
									shocks following trials Visual stimulus appeared in same location.					
Koppen &	1	14	Adult	24	simple	N	40:40:20	2	Press both keys	-	-	✔	✔	✔

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
Spence (a), 2007	2	14	Adult	20		N	33:33:33	2				✔	✔	✔
	3	12	Adult	25		N	40:40:20	3	Press separate key			✔	✖	✔
	4.1	20	Adult	24		N	40:40:20	2	Press both keys	- (total i.e. visual cues and auditory cues)		✖	✖	✖

Author	Exp.	n	Age: Group	Age: M	Stimuli: Type	Stimuli: Matched	Stimuli: Ratio	Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for: Colavita	Unimodal vs. Bimodal RT: Visual	Unimodal vs. Bimodal RT: Auditory
	4.2									V (visual cue)		✔	✔	✔
	4.3									A (auditory cue)		✔	✔	✔
Sinnett, Spence & Soto-Faraco,	1	24	Adult	-	Complex	N	40:40:20	3	Press a separate key	-	-	✖	✖	✖
	2	54			Complex	N	40:40:20	3				✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
2007	4	24				N	33:33:33	3				✖	✖	✖
	5.1	18				N	60:20:20	3		V (more visual targets)		✖	✖	✖
	5.2	18				N	20:60:20	3		A (more auditory targets)		✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
	6.1	18			Complex	N	40:40:20	3		A (low auditory load)		✖	✖	✖
	6.2	18			Complex	N	40:40:20	3		V (low visual load)		✖	✖	✖
Koppen & Spence (b),	1	18	Adult	22	simple	N	20:20:60	2	Press both keys	-	-	✔	✔	✖
	2.1	12		22			5:5:90					✔	✔	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
2007	2.2						25:25:50					✔	✔	✖
	2.3						45:45:10					✔	✔	✖
Koppen & Spence (c), 2007	1.1	36	Adult	23	simple	N	40:40:20	2	Press both keys	-	C (same position (13°))	✔	✔	✔
	1.2										I (different	✔	✔	✔

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
											position (13°))			
	1.3										C (same position (26°))	✔	✔	✔
	1.4										I (different position	✔	✔	✔

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
											(26°))			
Koppen & Spence (d), 2007	1	22	Adult	23	simple	N	40:40:20	2	Press both keys – stimuli presented at various stimulus onset asynchrony's-	-	-	✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
									overall errors considered for analysis.					
Koppen, Alsius & Spence,	1.1	12	Adult	21	Complex	N	40:40:20	2	Press both keys	-	C	✔	✔	✔
	1.2										I	✔	✖	✖
	2.1	30		21				3	Press separate		C	✔	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
2008	2.2								key		I	✔	✖	✖
	3.1	15		23	Complex						C	✔	✖	✖
	3.2										I	✔	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
Sinnet, Soto-Faraco & Spence , 2008	1.1	22	Adult		complex	N	40:40:20	3	Press separate key	-	-	✖	✖	✖
	1.2							1	Press single key to all targets			✖	✖	✖
	2	20						1	Press single key	-	-	✖	✔	✔

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
									to all targets					
Koppen, Levitan, & Spence, 2009	1	22	Adult	20	simple	Y	25:25:25:25(no target)	2	Press both keys			✖	✖	✖
Hecht & Reiner	1	12	Adult	24.6	simple	N	40:40:20	3	Press separate	-	-	✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
(2009)									key					
Van Damme et al, 2009	1.1	20	Adult	19.5	simple	N	40:40:20	3	Press separate key	(visual threat baseline)	-	✔	✖	✖
	1.2									V (visual threat – received infrequent shocks		✔	✖	✖

Author	Exp.	n	Age: Group	Age: M	Stimuli: Type	Stimuli: Matched	Stimuli: Ratio	Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for: Colavita	Unimodal vs. Bimodal RT: Visual	Unimodal vs. Bimodal RT: Auditory
										following visual stimuli)				
	1.3	20								(auditory threat baseline)		✔	✖	✖
	1.4									A (auditory threat-		✔	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
										received infrequent shocks following auditory stimuli)				
	1.5	17								Control		✔	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
										baseline				
	1.6									control		✔	✖	✖
Ngo, Sinnett, Soto-Faraco, & Spence,	1	24	Adult	28	Complex	N	40:40:20	3	Press separate key- detect immediate repetition	-	-	✔	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
2010														
Ngo et al, 2011	1	20	Adult	28	Complex	N	40:40:20	3	Press separate key- respond to repeated (n-1) targets	-	-	✔	✖	✖
	2	18		27	Complex							✔	✖	✖

Author	Exp.	n	Age: Group	Age: M	Stimuli: Type	Stimuli: Matched	Stimuli: Ratio	Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Colavita	Visual (Unimodal vs. Bimodal RT)	Auditory (Unimodal vs. Bimodal RT)
	3	16		24	Complex							✔	✖	✖
	4	24		25	Complex				Press separate key- detect immediate repetition			✔	✖	✖
Moro &	1	11*	Adult	24.6	Complex	N	40:40:20	1	Press one key to	-	-	✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
Steeves, 2012									all targets					
	2							3	Press separate key for bimodal targets	-	-	✔	✖	✖
Moro & Steeves,	1	11*	Adult	28.3	Complex	N	40:40:20	1	Press one key to all repeats	-	-	✖	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
2013	2							3	Press separate key for bimodal repeats	-	-	✔	✖	✖
Stubblefield, Jacobs, Kim, & Goolkasian,	2.1	35	Adult	24	complex	N	40:40:20	1	Press single key to predefined visual target – Incongruent	V	-	✖	✔	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
2013									auditory distractor present.					
	2.2								Press single key to predefined auditory target-Incongruent	A		✖	✖	✔

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
									visual distractor present.					
	4.1	31		20					Press single key to predefined visual target- Incongruent auditory	V		✖	✔	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
									distractor present.					
	4.2								Press single key to predefined auditory target- Incongruent visual distractor	A		✖	✖	✔

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
									present.					
Nava & Pavani, 2013	1.1.1	14	Child	6.8	simple	N	40:40:20	2	Press both keys	-	-	✔	✔	✔
	1.1.2	14	Child	9.5		N	40:40:20	2				✔	✔	✔
	1.1.3	13	Child	11.7		N	40:40:20	2				✔	✔	✔

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
	1.2	10	Child	6.9		N	33:33:33	2				✔	✔	✔
Tsukiko & Desmarais, 2014	1	31	Adult	19	Complex	N	33:33:33	3	Press separate Key	-		✖	✖	✖
Yue, Jiang,	1.1	28	Adult	22.7	simple	N	40:40:20	2	Press both keys	-	C (both	✔	✔	✔

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
Li, Wang, & Chen, 2015											near)			
	1.2										C (both far)	✔	✔	✔
	2.1	20		22.6						V	I (auditory far - visual near)	✔	✔	✔
	2.2									A	I (Visual far	✔	✔	✔

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
											- auditory near)			
Willie & Ebersbach, 2016	1.1.1	28	Child	6.39	Complex	N	33:33:33	3	Press a separate key		total	✔	✖	✖
	1.1.2										I	✔	✖	✖
	1.1.3										C	✔	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
	1.2.1	30	Child	8.87							total	✔	✖	✖
	1.2.2										I	✔	✖	✖
	1.2.3										C	✔	✖	✖
	1.3.1	28	Adult	25.96							Total	✔	✖	✖
	1.3.2										I	✔	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
	1.3.3										C	✔	✖	✖
	2.1.1	19	Child	6.42			25:25:50				Total	✔	✖	✖
	2.1.2										I	✔	✖	✖
	2.1.3										C	✔	✖	✖
	2.2.1	17	Child	9.06							Total	✔	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
	2.2.2										I	✔	✖	✖
	2.2.3										C	✔	✖	✖
	2.3.1	23	Adult	27.61							Total	✔	✖	✖
	2.3.2										I	✔	✖	✖
	2.3.3										C	✔	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
	3.1.1	18	Child	6.39	Complex						Total	✔	✖	✖
	3.1.2										I	✔	✖	✖
	3.1.3										C	✔	✖	✖
	3.2.1	24	Child	9.13							Total	✔	✖	✖
	3.2.2										I	✔	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
	3.2.3										C	✔	✖	✖
	3.3.1	20	Adult	28.7							Total	✔	✖	✖
	3.3.2										I	✔	✖	✖
	3.3.3										C	✔	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
Monem & Fillmore, 2016	1.1	25	Adult	25.4	complex	N	33:33:33	1	Press the key whenever you see a visual, auditory or audio-visual target (alcohol)	-	-	✖	✔	✖
	1.2							1	Press the key			✖	✔	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
									whenever you see a visual, auditory or audio-visual target (office supplies)					
	2.1							3	Press a separate			✔	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
									key whenever you see a target (office supplies)					
	2.2								Press a separate key whenever you see a target (alcohol)			✔	✖	✖

Author	Exp.	n	Age		Stimuli			Keys (n)	Instructions on bimodal trials	Attentional Manipulation	Congruency	Possible to calculate effect sizes for:		
												Colavita	Unimodal vs. Bimodal RT	
			Group	M	Type	Matched	Ratio						Visual	Auditory
Stekelenburg & Keetels, 2016		20	Adult	21.1	simple	N	33:33:33	3	Press separate key	-	-	✖	✖	✖

Table 1. Details of experiments considered for analysis broken down by experiment and condition. Tick boxes indicate whether studies reported the details necessary calculation of Cohens d_{av} (i.e. sample size, mean and standard deviation or standard error). Abbreviations within the “Attentional Manipulation” and “congruency” columns are as follows; C=Congruent, I=Incongruent, V=visual, A=auditory. If nothing is stated then this was either not manipulated or

not reported within the obtained article. * Value indicates n for healthy control condition. For example, Moro & Steeves, (2012;2013) both included 11 participants who had undergone monocular enucleation, these participants were not included.

factor	df	QM	p
Ratio	5	2.8086	0.7295
Response Keys	1	.0067	.9348
Stimulus Category	1	.2429	.6221
Congruency	2	.2826	.8682
Attentional Manipulation	2	.0826	.9595
Age Group	1	23.1934	<.0001

Table 2. Statistics resulting from additional analyses of variance (ANOVAs) exploring the effect of each factor upon the intercept of the mixed model (i.e. the overall effect size of the Colavita effect). One factor, age, significantly influenced the effect size of the Colavita effect. Df=degrees of freedom, QM= omnibus test statistic.

factor	**df**	**QM**	**p**
Ratio	5	28.9657	<.0001
Response Keys	1	2.0901	.1483
Stimulus Category	1	18.7978	<.0001
Congruency	2	6.6510	.0360
Attentional Manipulation	2	.8065	.6681
Age Group	1	3.2004	.0736
Matched	1	2.6295	0.1049

Table 3. Statistics resulting from additional analyses of variance (ANOVAs) exploring the effect of each factor upon the intercept of the mixed model (i.e. the overall effect size for the effect of auditory stimuli on visual target detection). Three factors, ratio, stimulus category and congruency, significantly influenced the effect of auditory stimuli upon visual target detection. Df=degrees of freedom, QM= omnibus test statistic.