Speed of Processing, Time, and Interference in the Attentional Blink: Application to Children.

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Abstract – The Attentional Blink (AB) represents the limits of temporal processing capacity and is estimated using a rapid serial visual presentation (RSVP) in which items (commonly letters or numbers) are presented for 100msec, one after the other, in the same spatial location. When two targets are embedded within the sequence, the inter-target interval required to correctly report both targets reflects the AB (approximately 500-700msec in adults). In a series of 3 studies, this investigation controlled for individual speed of processing and evaluated the application of the AB in children (between 6 and 12 years of age). Speed of processing was controlled using an adaptive, single-target RSVP procedure, whereby exposure duration required for 70.7% accuracy was estimated. This was then applied to dual-target RSVP. Study 1 suggested that individuals with faster speed of processing had less of an AB. However, this was confounded by differences associated with RSVP duration: for those with brief exposure durations, RSVP duration was shorter. Study 2, controlling for RSVP duration, suggested that distracters produced an interference confound: those with briefer durations were presented with more items in the same RSVP duration. In Study 3, distracter items between targets were removed. The time interval between targets required for correct report was estimated using an adaptive procedure, where the duration of a blank inter-target interval was varied. This suggested that processing speed was related to AB estimates. It is recommended that these factors, as well as inattention, be considered when applying the AB to developmental and group-difference research.

Index Terms – Attentional Blink, Speed of Processing, Children, and Development.

INTRODUCTION

The Attentional Blink (AB) is a robust phenomenon, reflecting a temporal limitation of information processing. It is apparent when searching for two targets separated by a temporal interval, where there is a marked reduction in accuracy when detecting the second-target (T2) for approximately 500msec following the appearance of the first-target (T1)[1]. This disturbance was originally considered analogous to an eye-blink during which no new information can be processed, however, recent evidence suggests that the information 'missed' is superficially processed and merely escapes conscious recall [2]. A common premise of AB models argues that limited cognitive resources are available for target consolidation which restricts the amount of information that can be processed across time [3].

The majority of AB procedures involve a rapid presentation of information, predominantly in the visual modality (rapid serial visual presentation: RSVP). This involves the sequential display and removal of items, commonly letters or numbers, in the same spatial location. The stimulus-onset asynchrony is usually set at 100msec, with or without a blank inter-stimulus interval. This timing is kept constant across all participants in order to gain a representation of group performance. For a schematic illustration see Fig 1.

Group application of psychophysical tasks however, limits the accuracy of the information gathered and it may also obscure important differences between groups as well as individuals [4, 5]. When examining individual differences in the time needed to correctly identify the letters T or A in schizophrenic patients, Badcock et al. [4] discovered that the required duration was related to the risk of psychosis: patients at greater risk required longer durations to reach equivalent levels of accuracy. This duration reflects speed of information processing, slower in schizophrenic patients. In this scenario, prior research into group differences can be considered as confounded by this factor. This also applies to the examination of group differences in the AB literature [6-8].

In an attempt to control for individual differences in speed of information processing within an AB experiment, single-target performance can be assessed. Alternative techniques for doing this include utilizing a method of constant stimuli through which a psychometric curve is estimated and the duration is selected on the basis of a point

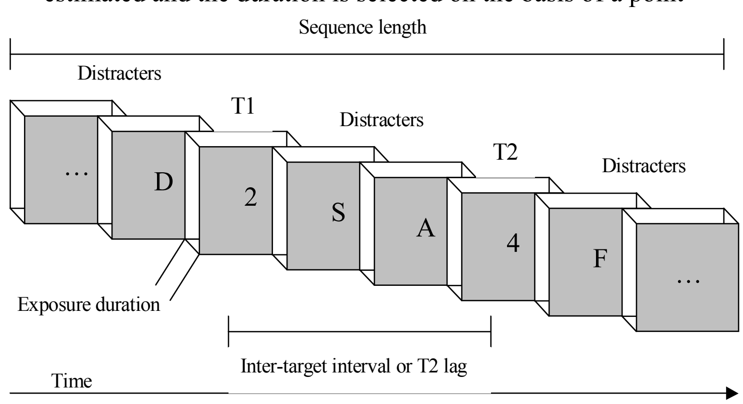

Fig. 1 A schematic version of the standard Attentional Blink presentation for this study. The rapid serial visual presentation includes distracter letters, the first target (T1), inter-target distracters, the second target (T2), and more distracters. Each item is presented for an individually set exposure duration. The position of T2 relative to T1 is the inter-target interval or T2 lag. If the exposure duration were set to 100msec, then the illustrated T2 lag of 3 items would correspond to 300msec.

of accuracy along this curve, or an adaptive procedure where a single level of accuracy is estimated. For the current research, the adaptive method was used. An advantage of estimating and controlling for single-target accuracy in the AB is that this gives a clear indication of baseline performance against which the cost of dual-target tasks can easily be assessed.

AB investigations have predominantly involved adult populations. Those carried out with children have examined developmental disorders [9-11] and rarely carefully considered what control children's performance might look like. Children between the ages of 6 and 12 provide a useful population for the current research as there is likely to be a large variation in cognitive abilities [12] which will allow for a comparison of the AB effect for a wide range of processing speeds [13]. The experiments reported here aimed to examine the impact of controlling for individual differences in speed of processing within the AB.

The three studies were completed in two, half-hour sessions, on a single day. The order of the first two studies was counterbalanced across two groups of children and Study 3 was always conducted last. The task requirements were held constant across all studies. There were two tasks: a single-target and a dual-target task. In the single-target task, participants were asked to identify one number (1, 2, 3, or 4) in a series of letters. In the dual-target task, participants were asked to identify two numbers in a series of letters.

Study 1: Speed of processing in the AB.

In the first study all observers were presented with the same sequence of stimuli, however, item exposure duration (see Fig. 1) was adjusted for individual processing speeds estimated in the single-target task. As a result, RSVPs in the dual-target task of a given sequence length were briefer for children with short exposure duration and slower for the children with longer exposure duration. If the AB is a time-locked phenomenon, corresponding from 500 to 700msec, equating for speed of processing in item exposure duration should result in all observers displaying a similar AB effect.

METHOD

Participants

There were 21 children aged from 6 years 11 months, and 11 yrs, 0m (*M* = 8.64, *SD* = 1.22) in this research. Nine were male. They were recruited from local primary schools and were participating in a holiday research program (Project K.I.D.S.) at The University of Western Australia. These children took part in all three studies.

Procedure

The stimuli consisted of black, uppercase characters of Arial font, subtending approximately 1.34º of visual angle in height and 0.95º in width. Targets, T1 and T2 were randomly selected from the numbers 1, 2, 3, and 4. Distracters were randomly selected letters of the alphabet, excluding I, O, and Q as they do not provide adequate masking properties, and Z and E as they may be confused with the targets (2 and reversals of 3). All characters were presented on a light-grey background.

Participants pressed a button to initiate each trial. A 'Ready?' cue appeared on the screen followed by seven to 14 items before the T1 position and 22 items following the T1 position. T2 was placed at lags of 5, 10, 15, or 20 items following the T1 position. Note: these numbers correspond to different time intervals, dependent upon observer single-target processing speed with faster single-target processing corresponding to shorter intervals.

Single-target task

Accuracy in the single-target task was estimated by adjusting the exposure duration of all stimuli within the RSVP using a PEST procedure set at 70.7% correct identification, a conventional point representing a steep gradient on the psychometric curve at this point. There were two separate runs of 50 trials. Exposure duration commenced at 156.2msec (11, 14.2msec frames) and was adjusted using frame steps. Duration thresholds were estimated as the average of the last four staircase reversals and the lowest threshold from either run was used in the dual-target conditions. Only a single-target was presented from position 12 to 29 in the sequence and was always followed by at least two items. Only one target was presented and participants were required to report it when prompted at the end of each trial. Responses were entered by the participant using a button box with four options labelled 1, 2, 3, and 4. Each run consisted of 3 blocks of 17, 17, and 16 trials.

Dual-target task

The duration of item exposure determined in the single-target task was used in the dual-target task. The targets were never the same number in a single-trial. At the end of each trial, participants were asked to report two numbers. Responses were entered by the participant using a button box. There were two blocks of 30 trials with 15 estimates at each T2 lag.

RESULTS AND DICUSSION

The median exposure duration of the stimulus, derived from the single-target task, was 4 frames (56.8msec): durations ranged from 2 (28.4) to 7 (99.4) frames.

To determine whether Study order impacted upon target accuracy, independent sample t-tests were conducted between the two groups of children for overall T1 and T2 accuracy. The group which completed Study 1 first had higher accuracy for both of the targets: T1, M_{1_T1}= 0.58 (*SD*=0.15), M_{2_T1}=0.46 (0.15); T2, M_{1_T2}= 0.47 (0.15), M_{2_T2}=0.36 (0.11). Neither of these effects was statistically significant; T1, $t(19)=1.73$, $p=.100$, Cohen's d = 0.76; T2, $t(19)=1.93$, $p=.069$, Cohen's d = 0.85, suggesting that Study order did not influence identification accuracy for either target and therefore was not factored into further analyses.

To examine the AB effect, the identification accuracy of T1 and T2 was calculated for each level of T2 lag. This was completed for raw accuracy as well as contingent upon the other target being correctly reported: for example, T1 given that T2 was correct (T1|T2) was based on those trials for which T2 was correctly identified. These values are

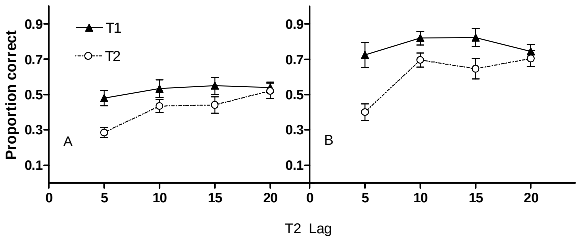

Fig. 2 T1 and T2 raw (Panel A) and contingent (Panel B) accuracy for each T2 lag. Raw estimates are based upon all available information whereas contingent accuracy is based upon only those trials for which the other target was correctly identified: for example, contingent accuracy for T1 was based upon trials for which T2 was correctly identified. Error bars represent the standard error of the mean.

displayed in Fig. 2, Panel A with raw accuracy, and Panel B with contingent accuracy. Raw accuracy was lower than contingent accuracy for both targets, $F_{(1,20)}$=135.21, p<.001, partial-η^2=.871. As the duration of the stimuli was set to deliver 70.7% accuracy, it would be expected that T1 overall and T2 at the later lags should reach this single-target accuracy. This being the case in the contingent and not the raw accuracy data suggests that, on approximately 20 to 30% of trials (the difference between raw and contingent accuracy for each target), children may not have been applying adequate attention to the task. Given this consideration, the lower accuracy for raw detection may reflect inattention. Therefore, contingent accuracy was used to assess the AB effect.

There was a main effect of target, $F_{(1,20)}$=25.87, p<.001, partial-η^2=.564, lag $F_{(3,60)}$=6.85, p<.001, partial-η^2=.255, and a significant target by lag interaction, $F_{(3,60)}$=5.76, p=.002, partial-η^2=.223. The main effects reflected T1 being reported with higher accuracy than T2 and later targets with greater number of distracter items between them (i.e., higher lags) were reported with higher accuracy. The interaction reflected lower accuracy for T2 when it appeared closer in time to T1, which is the AB effect.

The pattern of this group data suggests that the AB is recovered after a T2 lag of 10 items when compared to the single-target task accuracy of 70.7%, t(20)=0.28, p=*.782*. Given that individual exposure durations ranged from 28.4 to 99.4msec, this would indicate that the AB is associated speed of processing: 10 items representing time intervals of approximately 300 to 1000msec. This reflects individual differences in AB duration. Importantly, group summaries of this information may be somewhat misleading.

To explore this point, the data were divided into three exposure duration groups: < 45msec, 45 to 80, and > 80. If the duration of the inter-target interval and not the number of between target items was an important factor, brief exposure durations would be associated with a greater drop in T2 accuracy as T2 would be presented closer to T1. For completeness, both T1|T2 and T2|T1 accuracy rates across lags for the three exposure duration groups are displayed in Fig. 3: Panel A represents < 45msec, B: 45 to 80msec, and C: > 80msec. Statistical comparisons were only conducted for the AB information, i.e., T2|T1 accuracy. There was a significant main effect of exposure duration $F_{(2,18)}$=2.98, p=.038, lag, $F_{(1,54)}$=10.92, p<.001, partial-η^2=.378, partial-η^2=.249, and a non-significant exposure duration by lag interaction, $F_{(6,54)}$=0.315, p=.93, partial-η^2=.034. The main effect of exposure duration reflected a pattern of brief exposure durations being associated with greater AB effects. The main effect of lag related to the AB effect with lower accuracy when T2 was presented closest to T1.

Overall accuracy was lower for those children with briefer exposure durations suggesting an association between speed of processing and the AB. Closer examination of performance at the three levels of exposure duration suggests that the duration assigned to the long duration group may be inaccurate. Inspection of Fig. 3 suggests that despite an effort being made to control for individual differences in single-target task difficulty, as a group, those children with longer exposure duration demonstrated greater success in the task for both targets.

Controlling for target difficulty by modifying exposure duration suggested that there are individual differences within the AB, which appear to be related to speed of processing. The results indicated that, independent of exposure duration, the AB ended when T2 appeared at lag 10. This represents inter-target durations of approximately 400, 700, and 900msec dependent upon the exposure duration (p>.410 for each group for lag 10 accuracy compared using paired sample t-tests with single-target task accuracy of 70.7%). These results indicate that the AB cost was higher for these children with faster speed of processing, although, it was perhaps a briefer period of AB interference. This may suggest that children with faster processing speeds are better able to focus their attention towards a specific goal or alternatively, the nature of the procedure may have caused this difference.

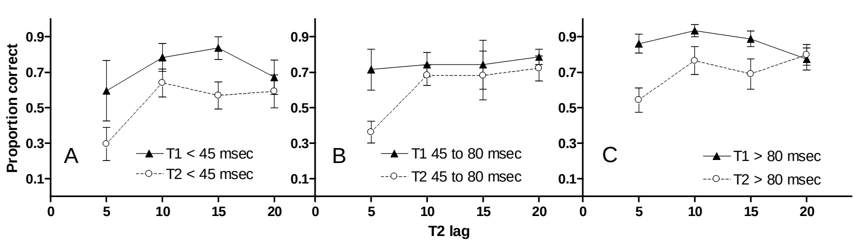

Fig. 3 T1|T2 and T2|T1 accuracy across four T2 lags for exposure duration groups: Panel A: < 45msec, B: >45, < 80, and C: > 80. There were seven children in each group and the error bars represent the standard error of the mean.

Study 2: Inter-target intervals in the AB

Study 2 was designed to control for the duration of inter-target intervals as opposed to the relative position of targets. Whereas T2 appearing at lag 10 in Study 1 corresponded to inter-target intervals of approximately 300 to 1000msec depending upon exposure duration, the timing of inter-target intervals in Study 2 was fixed between participants.

METHOD

Procedure

The procedure was the same as in Study 1 with one modification to the dual-target condition. T2 positions were based upon time intervals, tailored to individual exposure durations estimated in the single-target condition. T2 appeared after approximately 300, 600, 1000, or 1500msec following T1. Differing item exposure durations meant that there were differing numbers of inter-target distracters: Children with brief exposure durations were subject to greater numbers of inter-target distracters (see Fig. 1) within the same RSVP duration. There were a total of 60 trials in two blocks, with 15 estimates at each T2 time interval.

RESULTS AND DISCUSSION

To determine whether the order of studies impacted upon target accuracy, independent sample t-tests were conducted between the two groups of children for overall T1 and T2 accuracy. The group which completed Study 1 first had higher accuracy for T1 but lower accuracy for T2: T1, M_{1_T1}= 0.56 (*SD*=0.16), M_{2_T1}=0.41 (0.14); T2, M_{1_T2}= 0.39 (0.16), M_{2_T2}=0.37 (0.10). This effect was significant for T1, *t*(19)=2.29, *p*=.034, Cohen's *d* =1.01, but not for T2, *t*(19)=0.37, *p*=.715, Cohen's *d* = 0.16. This suggests that practice effects were limited to the first target in this study. As the main aims of this research pertain to the AB and thus T2, the analysis was not modified for this difference.

To examine the AB effect, T1 and T2 accuracy was calculated for each level of inter-target interval. This was calculated as raw accuracy as well as contingent upon the other target being correctly reported, as in Study 1. These values are displayed in Fig. 4, Panel A with raw accuracy, and Panel B with contingent accuracy. Raw accuracy was lower than contingent accuracy for both targets, $F_{(1,20)}$=151.23, *p*<.001, partial-η^2=.883. As in Study 1, it appears that inattention occurred on approximately 20% of trials. Contingent accuracy was used for further analysis.

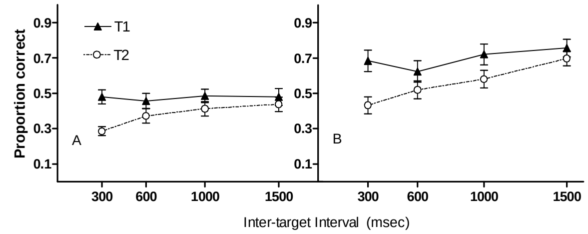

Fig. 4 T1 and T2 raw (Panel A) and contingent (Panel B) accuracy for each inter-target interval in msec. Raw estimates are based upon all available information whereas contingent accuracy is based upon only those trials for which the other target was correctly identified: for example, contingent accuracy for T1 was based upon trials for which T2 was correctly identified. Error bars represent the standard error of the mean.

There was a main effect of target, $F_{(1,20)}$=10.21, *p*=.005, partial-η^2=.338, inter-target interval, $F_{(3,60)}$=4.07, *p*=.011, partial-η^2=.169, and a non-significant target by inter-target interval interaction, $F_{(3,60)}$=2.69, *p*=.054, partial-η^2=.118. The main effects reflected T1 being reported with higher accuracy than T2 and targets at greater inter-target intervals being reported with higher accuracy.

The main effects of target and inter-target interval are of a greater magnitude in this study where the temporal position is dependent upon inter-target time and not the number of inter-target items. For comparison to Study 1, the current data were also segregated into three exposure duration groups: < 45msec, >45, < 80, and > 80. In accordance with the time-locked nature of the AB, there should be little difference between the groups. T1|T2 and T2|T1 accuracy for the four inter-target intervals and three exposure duration groups is displayed in Fig. 5.

There was a non-significant main effect of exposure duration, $F_{(2,18)}$=2.23, *p*=.136, partial-η^2=.199, a significant main effect of inter-target interval, $F_{(3, 54)}$=5.98, *p*=.001, partial-η^2=.249, and a non-significant exposure duration by inter-target interval interaction, $F_{(6, 54)}$=1.27, *p*=.287, partial-η^2=.124. Despite a non-significant effect of exposure duration, there was a trend for brief exposure durations to be associated with greater AB effects. The main effect of inter-target interval related to the AB effect with lower accuracy when T2 was presented closest to T1. Overall accuracy was lower for those children with briefer exposure durations suggesting that a factor associated with speed of processing may underpin the AB.

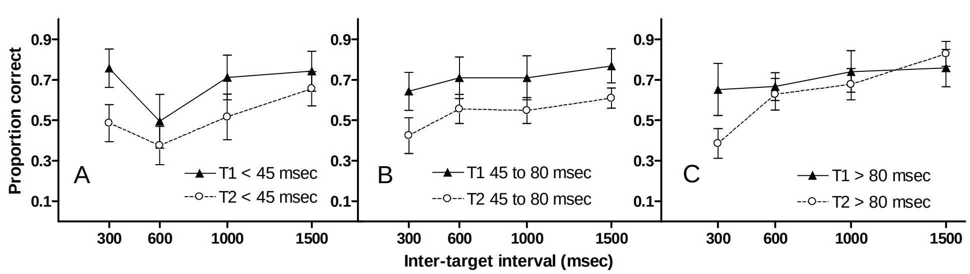

Fig. 5 T1|T2 and T2|T1 accuracy across four inter-target intervals for exposure duration groups: Panel A: < 45msec, B: >45, < 80, and C: > 80. There were seven children in each group and the error bars represent the standard error of the mean.

Closer examination of performance at the three levels of exposure duration suggests that the exposure duration derived in the single-target condition operated more effectively in Study 2. This is reflected in a more equivalent level of accuracy across groups. Inspection of Fig. 5 suggests that T1 accuracy was similar across the groups and only T2 accuracy is visually different. There is a trend of a greater impact in the brief exposure duration group and, in a comparison of < 45 and > 80msec groups, there was a statistically significant difference with those in the longer group showing less AB effect, $F_{(1, 12)}$=3.29, *p*=.047, partial-η^2=.215. Note: the longer exposure group reached baseline accuracy (70.7%) by 1000msec, *t*(6)=1.01, *p*=.350, whereas the brief exposure group reached baseline accuracy by 1500msec, *t*(6)=1.68, *p*=.143. The nature of this presentation was such that brief exposure durations included more distracter items between the targets. At an inter-target interval of 300msec, the 45msec group observed 7 or 9 distracters before T2 whereas in the > 80msec group there were approximately 4 or 5 distracters. This suggests that the distracter items may have an interference effect or provide a greater backward masking when there are more presented in a short period of time.

Study 3: Distracter interference in the AB

Study 3 was designed to minimize the effects of distracter items within inter-target intervals. In the previous studies, children requiring brief exposure durations to attain single-target baseline levels demonstrated greater AB effect. This is counterintuitive under the premise that the AB is associated with processing speed. If single-target processing is faster it can be expected that consolidating resources would be available sooner for the second target, which would result in less of an AB effect. If the greater number of distracter items is underpinning this interference, removing the distracters between the targets should remove this confound. The Study 3 procedure involved the presentation of an adaptive, blank inter-target interval, with the aim of gaining an uncontaminated estimate of AB recovery. Where Study 1 and 2 included multiple distracters between T1 and T2, Study 3 included only two distracters between targets to mask T1 followed by the blank interval (see Fig. 1 for standard procedure).

METHOD

Procedure

Item exposure duration was based upon the original single-target condition. The dual-target procedure was altered by inserting blank inter-target intervals. This inter-target interval duration was modified using an adaptive method based upon successful identification of T2, similar to that for estimating the single-target exposure duration. If T2 was correctly identified on two consecutive trials, the interval was decreased by a single frame (14.2msec). If T2 was incorrectly identified, the interval was increased. The sequence included, 7 to 9 distracter items, followed by T1, then two masking distracters followed by a blank interval of adaptive duration, followed by T2 and 7 to 9 distracters (see Fig. 1 for the standard display). There were 60 trials in two equal blocks.

RESULTS AND DISCUSSION

The mean inter-target duration needed for baseline T2 performance was 799.81msec (min = 333.05, max = 1618.80, *SD* = 346.97). In examining the individual differences in AB duration it would be expected that more developed children would have an effect more inline with the adult literature. Using age as a gauge of development, it would be expected that older children would exhibit less of an AB. A bivariate correlation supported this pattern but the relationship was not significant, *r* = -.348, *p*=.061 (one-tailed).

Speed of processing can be considered to be an indicator of individual differences in cognitive performance [13]. Thus, it would be expected that faster speed of processing should be related to more efficient cognitive functioning, suggesting that faster speed of processing should be associated with lesser AB effects. A bivariate correlation supported this pattern and was statistically significant, *r* = .441, *p*=.023 (one-tailed). This suggests that speed of processing, and potentially some developing cognitive function, is related to the AB.

GENERAL DISCUSSION

This exploration into the AB attempted to control for individual differences in speed of processing by modifying the exposure duration of all the items within a RSVP procedure. By equating single-target accuracy across participants, it can be considered that the data derived give a clearer representation of the experimental manipulations employed. There were three main findings: 1. The magnitude of the AB effect is related to speed of processing, 2. Increasing the number of distracters increases the AB effect and, 3. As a group, children appeared inattentive on approximately 20-30% of trials.

1. The magnitude of the AB effect is related to speed of processing.

The results from Study 1, where T2 was placed at particular item lags following T1, indicated that T2 was not captured by the AB effect when it was presented at a lag of 10 items following T1. Dependent upon the participant's exposure duration, this recovery related to time intervals from approximately 300 to 1000msec: those with a faster speed of processing were affected for shorter durations of time. This finding was supported in Study 3 which involved a more sensitive, adaptive estimation of the time interval required to recover from the AB. The AB estimate was not significantly related to age. However, strategies governing speed of processing (perhaps executive functions [12]) tasks may be a more sensitive measure of development than age [13].

2. Increasing the number of distracters between targets increases the AB effect.

When examining the time-locked nature of the AB, T2 was presented at approximate inter-target intervals following T1. However, this procedure directed that briefer exposure durations included more distracter items between targets. This resulted in greater AB effects in those children with brief exposure durations (Study 2), which can be explained using interference models of the AB [14] or task difficulty in terms of backward masking [15, 16]. Interference models suggest that distracters provide competition for entry into a sensory store. The more information temporally surrounding the targets increases the difficulty of this task. Similarly, the degree of masking produced by distracters may influence task difficulty. These arguments account for the finding that briefer exposure durations (i.e., faster speed of processing) were associated with greater AB effect compared to the effects observed for longer exposure durations. The simplest way of controlling for this confound seems to be a minimalist procedure adopted by Duncan et al. [17], including two targets and their respective masks.

3. As a group, children appeared inattentive on approximately 20-30% of trials.

When examining the differences between raw target accuracy and contingent target accuracy, the latter appeared to be reflective of expected accuracy (Study 1 and 2). Specifically, as single-target accuracy was set to be 70.7%, accuracy unaffected by the AB should correspond to this level of performance. Raw T1 performance and T2 performance at greater lags was observed to be 20-30% lower than the expected level whereas contingent accuracy was around this expectation. This suggests that the contingent accuracy was a better estimate of performance. It can be argued that in 20-30% of trials, children in this study were not able to complete the task as might be predicted by their single-target performance. This may be related to fatigue or task difficulty as well as distraction. The major implication is that children require more trials at each inter-target interval or lag in order to attain reliable estimates of their abilities. This may also be the case for clinical adult populations [6-8].

One further difference between Studies 1 and 2 is that T1 accuracy in Study 1 was much more variable than in Study 2. This variation can be attributed to the longer exposure-duration group who demonstrated higher accuracy than expected. This may relate to measurement error: if their set exposure durations were longer than required for 70.7% accuracy, greater inter-target intervals would result in a higher ceiling on performance. Considering the time intervals inherent in Study 1 for this group, T2 being presented at lag 10 (approximately 900msec) to 20 (1800msec), it is plausible that T1 was easily processed in this interval, resulting in higher accuracy. This would be less evident in Study 2 in which the intervals were not this extreme. However, T2 accuracy was not unexpectedly high in Study 1 which would be predicted if T1 was being more easily consolidated. This may relate to time intervals beyond the AB effect, being governed by a different process: memory may be the limiting factor at this stage. This requires independent investigation for solid inferences to be made.

In summary, utilizing an RSVP paradigm and controlling for individual differences in single-target accuracy, it was evident that differences in a dual-target task, the AB, were related to speed of processing. Individual differences, distracter stimuli, as well as inattention impacted upon the current investigation. These factors need to be considered when applying RSVP procedures in developmental and group difference settings. The novel AB procedures implemented allow for controlled comparisons between adult and child performance. The greater sensitivity inherent in these procedures also provides the best opportunity to date to make comparisons with other cognitive tasks, the underpinning mechanisms of which are better documented. These comparisons can lead to further developments in AB theory.

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