Brief Report: Impaired temporal reproduction performance in adults with Autism Spectrum Disorder

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Running Head: Temporal Reproduction in ASD

Abstract

Although temporal processing has received little attention in the autism literature, there are a number of reasons to suspect that people with autism spectrum disorder (ASD) may have particular difficulties judging the passage of time. The present study tested a group of 20 high-functioning adults with ASD and 20 matched comparison participants on a temporal reproduction task. The ASD group made reproductions that were significantly further from the base durations than did the comparison group. They were also more variable in their responses. Furthermore the ASD group showed particular difficulties as the base durations increased, tending to underestimate to a much greater degree than the comparison group. These findings support earlier evidence that temporal processing is impaired in ASD.

Key Words: Autism, Asperger's Syndrome, Time Perception, Temporal Reproduction

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To date there has been little systematic work investigating time perception in individuals with autism spectrum disorders (ASD). This is perhaps surprising since evidence from a variety of sources suggests that individuals with ASD may be impaired in their ability to accurately perceive time. Clinical accounts often report difficulties which relate to the judgement of time (Boucher, 2001). For example Wing (1996) interprets various behaviours shown by some people with ASD in terms of difficulties processing time, such as the desire to be reassured about future events and when they will occur, and the distress caused by unexpected changes to plans. In addition, the performance of people with ASD on certain cognitive tasks that relate to the passage of time (e.g. memory for temporal order) are consistent with temporal processing difficulties (see Bennetto, Pennington & Rogers, 1996; and Poirier & Martin, 2008).

Time perception in the normal population is measured through a wide variety of tasks (see Grondin, 2003 for a review). Summarising the broad literature in this area is beyond the scope of the current paper. However, generally speaking, healthy humans (and animals) show a remarkable ability to perceive and remember the duration of events – although the durations involved in most of the research would perhaps be considered short by many, ranging from 50 ms to a few seconds.

When trying to characterise human time perception performance, most authors will examine how well durations are perceived or reproduced on

average and also consider the variability around the said mean. Overall, time perception behaviour appears very orderly and well captured by a number of quantitative models and laws (Ivry & Schlerf, 2008). For example, when the task is to reproduce a range of durations, accuracy in reproducing the presented intervals usually conforms to Vierordt's law (1898). According to this law, the shorter durations of the range will be overestimated while the longer durations will tend to be underestimated. With respect to the variability of performance, most often, a form of Weber's law applies in that variability in perceiving or producing intervals will tend to be a constant proportion of the mean presented duration (Wearden and Lejeune, 2008).

Relative to time perception in normal young adults, impaired temporal processing has been demonstrated in a range of clinical groups who are thought to share some degree of aetiological overlap with autism, including dementia (Perbal, Deweer, Pillon, Vidailhet, Dubois, & Pouthas, 2005), older people (Vanneste, Perbal & Pouthas, 1999), ADHD, (Barkley, Murphy and Bush, 2001), schizophrenia (Davalos, Kisley, & Ross (2003), and patients with frontal lesions (Picton, Stuss, Shallice, Alexander, & Gillingham, 2006). Moreover, converging lines of evidence have identified brain regions thought to be important in the judgement of time, including the frontal cortex, hippocampus, basal ganglia, and cerebellum (Meck, 2005). Notably, disruptions in all four of these brain structures have been linked to autism. Several authors have accounted for the impaired timing performance shown by the groups mentioned above in terms of executive functioning- particularly working memory (e.g. Vanneste et al., 1999, Barkley et al., 2001). Such explanations are compatible with executive functioning theories of autism,

which account for some of the characteristic behaviours of autism in terms of deficits in executive functioning (e.g. Russell, 1997).

One of the few studies to examine time processing in autism was conducted by Mostofsky, Goldberg, Landa, & Denckla (2000). A group of 11 children and adolescents with autism were presented with two pairs of 50ms tones. The first pair was separated by 550ms while the second pair were separated by a variable interval that was either longer or shorter than the first 550ms interval. Participants had to indicate if this second pair was shorter or longer than the first. No group differences were found on this task- the autism group performed equivalently to the matched comparison participants. While this finding suggests that time processing may be normal in ASD, the durations used in this task were brief and it is possible that differences may emerge over longer intervals, as has been observed in other clinical populations such as ADHD (Radonovich & Mostofsky, 2004), and patients with frontal lobe lesions (Mangels, Ivry, and Shimizu, 1998). Mangels et al. (1998) suggest that the frontal cortex may be primarily involved in judging durations of over 1 second, while sub-cortical structures, such as the cerebellum and the basal ganglia regulate shorter intervals.

Gowen & Miall (2005) called upon a range of tasks related to cerebellar function in testing a group of 12 adults with ASDs and 12 matched comparison participants. These tests included two timing tasks: synchronization, where a sequence of four beeps were presented and participants were required to press a button in time with the two last beeps,

and continuation, in which two beeps were heard and participants were required to complete a 4 beep sequence. The ASD group judged inter-stimulus intervals as being shorter, responded earlier, and were more variable in their responses.

Perhaps the most compelling experimental evidence for time perception impairment in autism was reported by Szelag, Kowalska, Galkowski, and Poppel (2004). They used a temporal-reproduction paradigm with a group of seven children with high-functioning autism (HFA) and seven typically developing children. Stimuli were presented for 10 different durations ranging from 1000 to 5500ms. After a 2000ms pause, the stimulus was re-presented, and participants were instructed to interrupt it (by pressing a key) when its duration was judged to be equivalent to the original. The HFA children were found to perform extremely poorly, producing durations of approximately 3000ms for all 10 actual durations.

More recently, Wallace and Happé (2008) examined the performance of 25 children and adolescents with ASDs on tests of time estimation, time production and time reproduction. The study used durations of 2, 4, 12, 15, and 45 seconds. In the time estimation task, participants were required to estimate the duration of the time period between the experimenter saying ‘go’ and ‘stop’. The time production task required the participants to say ‘go’ and then ‘stop’ when they thought an identified time period had passed. Finally, in the time reproduction task, each trial started with the experimenter saying ‘go’ and then ‘stop’, after which the participant was required to reproduce the

duration by saying ‘go’ and ‘stop’. In marked contrast to the Szelag et al. study, there were no group differences, with some evidence of more accurate performance in the ASD group on the time reproduction task.

The contrast in the findings between these two studies is marked, although there are many methodological differences between them. The Szelag et al. study used a very small sample of children who were not individually IQ matched. In contrast, the Wallace and Happé (2008) study used a much larger sample, although the task was not computer-based and the five study durations were tested only twice in each of the three conditions. In light of their conflicting findings, it seems clear that further experimentation in this area is necessary.

In summary, experimental evidence relating to time processing ability in people with ASDs has yielded conflicting findings. Mostofsky et al. (2000) found no evidence of temporal discrimination difficulties in young people with ASD over sub-second durations, while Wallace and Happé (2008) found no evidence of impairment in a similar age group on tests of time estimation, time production and time reproduction. In contrast, Gowen and Miall (2005) found evidence of impairment on two different timing tasks in adults, and Szelag et al. (2004) found severely impaired time reproduction performance in young children with ASD.

The aim of the present study was to test time reproduction in a group of high functioning adults with ASDs, using a similar paradigm to Szelag et al. (2004)

in which participants have to reproduce auditory tones of varying length. The present study addresses some of the methodological issues in previous studies, while also extending the research in this area to adults with ASDs. Through using adults with IQs within the normal range, it is assumed that any group differences (relative to a matched comparison group) can be primarily attributed to features of ASD. Should a deficit be found, the evidence for impaired time reproduction performance would be extended to adults with ASD, and add further experimental support to clinical observations that suggest that deficits in time perception are a cognitive characteristic of ASD. A greater understanding of time processing in people with ASD may help us to understand some of the characteristic behaviours of ASD, offer insights in terms of interventions to support people with ASD, as well as increase our knowledge of the neurocognitive basis of ASD.

Method

Twenty individuals with ASD (15 male, and 5 female) and 20 typical individuals (13 male, 7 female) took part in this experiment. Participants were group matched on Verbal IQ as measured by the WAIS-III^{UK} (The Psychological Corporation, 2000) and did not differ on Performance IQ, Full scale IQ or age. Details of age and psychometric scores are given in Table 1. All individuals with ASD were diagnosed by experienced clinicians and a review of available medical records and/or assessment with the Autism Diagnostic Observation Schedule (ADOS; Lord et al. 1989) confirmed that all met DSM-IV (American Psychiatric Association, 2000) criteria for Autism

Spectrum Disorder. A brief interview ensured that no comparison participant had a history of neuropathology or psychiatric illness. Individuals were paid standard University fees for their participation.

Materials

A computer program was designed using Authorware (ref) to conduct the experiment on a standard Hewlett Packard PC-compatible laptop computer. Participants responded using an external mouse device. The Authorware system clock has a 1ms resolution and has been found to have high accuracy and stability measuring event times (McGraw,Tew and Williams, 2000).

The auditory stimulus was a pure tone of 200Hz frequency, presented through the built-in speakers on the Hewlett Packard PC-compatible laptop computer. Each participant was first presented with a sample tone and asked if they could hear it adequately. In addition each participant was asked if they would like to adjust the volume of the tone. None of the participants felt this was necessary. Seven different durations- 0.5, 1.1, 1.7, 2.3, 2.9, 3.5, and 4.1 seconds - were presented, in random order.

Procedure

Participants were individually tested in a quiet room. Following the successful completion of the practice trials, participants were left to complete the experiment by themselves, removing any bias that the experimenter's presence might induce. Two practice trials (with feedback) were followed by 21 trials with feedback, and 21 trials without feedback, in this fixed order. The

first set of experiment trials (with feedback) served as training. Extended training periods are commonly used in the timing literature to reduce variance (e.g. Kanabus, Szelag, Kolodziejczyk, & Szuchnik, 2004).

Each trial started with the presentation of one of the 7 study tones. Then, the word ‘wait’ appeared for 2000ms in the centre of the screen (as in Szelag et al., 2004). A second tone was then presented along with a button in the centre of the screen with the word ‘Stop’ within it. Participants had to reproduce the study tone duration by clicking the ‘stop’ button when they judged that the second tone had lasted for as long as the study tone. On feedback trials, participants were then told whether their reproduced tone was too long or too short, and by how much (in seconds or fractions of seconds). Upon completing the experiment, participants were asked whether they had used any particular technique, such as counting to measure the elapsed intervals.

(Place Table 1 about here)

Results

We examined the results with the help of 3 measures, two of them essentially examine the accuracy of the average produced duration—albeit from different perspectives while the third concentrates on the variability of performance. Each will be described further below.

The raw time reproduction durations and absolute discrepancy scores can be found in Table 2.

Absolute difference

As a basic examination of reproduction accuracy, we calculated the mean absolute difference between the base duration and the reproduced duration. This was obtained for each participant and base duration. A three-way mixed analysis of variance (ANOVA) was conducted on this data with Group (ASD vs. Comparison) Base Duration (7 levels) and Trial Type (Feedback or No Feedback) as factors. There were main effects of Base Duration $F(6, 228)=36.90$, $p < .01$, and Group, $F(1,38)=14.52$, $p < .01$, but not Trial Type. There were also significant interactions between Base Duration and Group $F(6,228)=4.80$, $p < .01$, and Base Duration and Trial Type, $F(6,228)=2.14$, $p =0.05$, but not the 3-way interaction. When either VIQ of PIQ was added as a covariate these effects remained and increased in significance.

The group difference is apparent in Figure 1 which shows the data collapsed across trial type. The AS group produced tones that were on average 0.48 seconds away from base durations, compared to 0.30 seconds in the comparison group. Post-hoc analyses revealed significant between group differences at the following base durations: 1.7 seconds, $t(38) = 2.158$, $p =0.04$, 2.3 seconds, $t(38) = 2.282$, $p =0.03$, 2.9 seconds, $t(38) = 2.615$, $p =0.01$, 3.5 seconds, $t(38) = 3.232$, $p < .01$, and 4.1 seconds, $t(38) = 3.470$, $p < .01$.

(Place Figure 1 about here)

Mean judgement ratio

In accordance with Szelag et al. (2004), the mean duration judgement ratio (MJR): [(the mean reproduction interval length – study duration)/ study duration] was used as a further measure of accuracy. This measure indicates the degree to which responses are on average underestimations or overestimations. Values above zero reflect a tendency to overestimate, while negative values reflect underestimation. A three-way mixed factor ANOVA was conducted with Group, Base Duration and Trial type as factors. There was a significant effect of Base Duration, $F(6,228)=27.37$, $p < .01$, Trial Type $F(6,228)=7.76$, $p < .01$, but no effect of Group. There was not a significant interaction between Trial Type and Group or Base Duration, Trial Type and Group. There was a significant interaction between Group and Base Duration $F(6,228) = 6.14$, $p < .01$, which is illustrated clearly in figure 2: the ASD group tended to overestimate shorter durations and underestimate longer durations, relative to the comparison group.

(Place Figure 2 about here)

Mean coefficient of variation

Again, in accordance with Szelag et al. (2004), the mean coefficient of variation (MCV: (standard deviation/mean reproduction at a given base duration)*100)), was used as a measure of variability in responses. Higher scores indicate increased variability in response.

A three-way mixed factor ANOVA was conducted with Group, Base Duration and Trial type as factors. There was a significant effect of Base Duration, $F(6,228)=11.12$, $p < .01$, Group $F(6,38)=6.39$, $p < .05$, but not Trial Type. There was not a significant interaction between Trial Type and Group or Base Duration and Group, but the three-way interaction between Trial Type, Base Duration and Group was significant $F(6,228) = 2.50$, $p < .05$. Again, a two-way mixed factor ANOVA was conducted with Group and Base Duration as factors. The AS group were more variable in their responses; there was a significant effect of Base Duration on the MCV, $F(6,228)=11.68$, $p < .01$, and of Group, $F(1,38)=8.05$, $p < .01$. There was no significant interaction.

When asked whether they had used a counting technique during the experiment, only 4 people in the ASD group, and 3 people in the comparison group reported not counting. When these 7 people were excluded from the analysis, the results remained the same.

(Place Table 2 about here)

Discussion

The ASD participants in this study were found to be both less accurate at making time reproductions and more variable in their responses than the matched comparison group. In particular, as the base durations increased in

length beyond 2300ms, the ASD group showed decreasing accuracy relative to the comparison group, tending to underestimate their reproductions.

The present finding of impaired temporal reproduction performance is consistent with the data reported by Szelag et al. (2004) and Gowen & Miall (2005). In addition the pattern of reduced accuracy and increased variation was also reported by Gowen & Miall (2005) in their interval timing task (in which participants had to coordinate responses with a sequence of beeps), suggesting that this pattern of performance may be consistent across difference timing tasks.

Interestingly, the findings from the present study contrast with those of Wallace and Happé (2008). In their study, a group of children and adolescents with ASDs performed equivalently to a matched comparison group on a task of reproduction, with some evidence of superior performance. While it is difficult to directly account for this marked contrast with the present findings, the methodologies of the two studies were very different. In contrast to the Wallace and Happé study, the current experiment was computer-based and was conducted with adult participants. In addition, a greater number of trials per base duration were used, reducing variability. Also, in the present study, the intervals were filled with a continuous tone, which was not the case in Wallace and Happé's study.

Timing tasks such as the one used here have been described by some researchers as cognitively controlled tasks (Lewis & Miall, 2006), because they are assumed to involve cognitive processes such as memory and attention. These tasks are characterised by intervals which last in the seconds

range, are unpredictable, and irregular. Research has shown that these types of tasks are heavily associated with the right dorso-lateral-prefrontal-cortex, and seem to draw upon the same resources as both verbal and visuo-spatial working memory tasks (Lewis & Miall, 2006; Baudouin, Vanneste, Isingrini, Pouthas, 2006). This relationship with areas of the frontal cortex and working memory is very relevant to executive theories of autism, which conceive some of the characteristics of autism (such as restricted interests, and stereotypic behaviour), in terms of deficits in executive functioning. However, while there has been fairly consistent evidence for deficits in some aspects of executive functioning in autism, the evidence for working memory impairment has been more equivocal (see Poirier & Martin, 2008). Russell (1997) has argued that while working memory impairments are unlikely to be fundamental to autism, impaired performance can be observed when tasks combine a working memory load with the inhibition of a prepotent response. Perhaps it could be argued that a temporal reproduction paradigm fulfils these requirements: participants must maintain both the base duration and the reproduction duration in working memory, whilst inhibiting a prepotent response to end the reproduction duration. In a reproduction task, as the duration to be reproduced increases, the memory load increases accordingly (Barkley et al., 2001), placing a greater demand upon working memory.

Interestingly, the pattern of increasing underestimation with increasing duration length shown by the ASD participants in this study has also been observed in time reproduction studies with older adults (e.g. Vanneste, Perbal, & Pouthas, 1999, Perbal, Droit-Vollet, Isingrini, & Pouthas, 2002).

Similarities between adults with ASDs and older adults have been made in relation to other aspects of memory performance, such as free recall and task support (see Bowler, 2007). With respect to time reproduction, Baudouin et al. (2006) suggest that older adults underperform because of a decreased ability to store the internal timing pulses which determine performance. This would lead to systematic duration underestimation in a reproduction task. However, while a working memory interpretation may offer a potential explanation for the greater underestimation shown by the ASD group for longer durations, it cannot easily account for their greater tendency to overestimate shorter durations, as shown in Figure 2.

As the figure showed, the trend of overestimating shorter durations and underestimating longer durations was very orderly in both groups but stronger in the individuals with ASD. The results suggest that there is a form of 'regression toward the mean' in reproduced intervals, in the sense that reproductions appear biased in such a way that they are drifting towards the overall average of the presented durations. Interestingly, the crossover between underestimation and overestimation, on average, is very close to the arithmetic mean of the presented durations (i.e. 1.8 seconds).

In effect, this appears as an instance of Vierordt's law (1868). According to Vierordt's law (1868), when assessing time in retrospect, shorter durations tend to be overestimated, whereas longer durations tend to be underestimated; reviews of empirical work in the field report support for this law in many instances (Block & Zakay, 1997; Wearden & Lejeune, 2008).

How can these findings be interpreted? Although speculative, one idea that might warrant further investigation is the following. All participants seem to show regression towards the average presented duration: it is as if the prototypical duration that develops biases the memory for the most recent episode (see Hemmel & Steyvers, 2009 for a related idea and supportive findings). This bias appears stronger in individuals with ASD. This could be because the representation of the most recent episode is not as well maintained, i.e. short-term memory for recent information is somewhat affected in ASD – a suggestion for which there is some prior evidence for (Poirier & Martin, 2008). In other words, when the most recent information is not as easy to discriminate from prior episodes, prototypical or canonical representations will tend to influence recall more heavily. Further research will be needed in order to determine if this effect is stable and if it is specific to temporal information or extends to other dimensions.

In summary, the present study extends evidence of temporal reproduction difficulties in HFA children to a group of adults with ASDs. The magnitude of impairment found in this study is quite striking and systematic. These findings augment the emerging experimental evidence for time processing difficulties in autism, and like the findings of Gowen & Miall (2005), suggest that such impairments are present in high functioning adults with ASDs. Also, recently, Gepner and Feron (2009) offered a hypothesis accounting for various aspects of ASD behaviour, suggesting that many difficulties could be attributable to temporo-spatial processing disorders. The results presented here also point in the direction of temporal processing deficits. It will be important in future

research to expand the range of timing tasks used in order to gain a more detailed understanding of the time processing impairment in autism and uncover its cognitive and neurological basis.

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Table 1: Chronological Ages and IQ scores for the ASD and Comparison group.

	ASD (N=20)		Comparison (N=20)	
	Mean	SD	Mean	SD
Age (years)	36	13.4	35	10.8
VIQ[a]	107	14.8	108	13.8
PIQ[b]	105	18.9	106	18.8
FIQ[c]	106	17.3	108	16.4

[a] **Verbal IQ**

[b] **Performance IQ**

[c] **Full-Scale IQ**

Table 2: Raw Time Reproduction and Absolute Discrepancy Scores for the ASD and Comparison group (Standard deviations are reported in brackets)

Raw Time Reproduction

Duration (s)	AS (n =20)	COM (n =20)
0.5	0.64 (0.13)	0.57 (0.12)
1.1	1.30 (0.28)	1.14 (0.19)
1.7	1.78 (0.35)	1.67 (0.19)
2.3	2.20 (0.29)	2.26 (0.23)
2.9	2.64 (0.36)	2.75 (0.25)
3.5	2.95 (0.47)	3.28 (0.34)
4.1	3.27 (0.51)	3.72 (0.35)

Absolute Discrepancy Scores

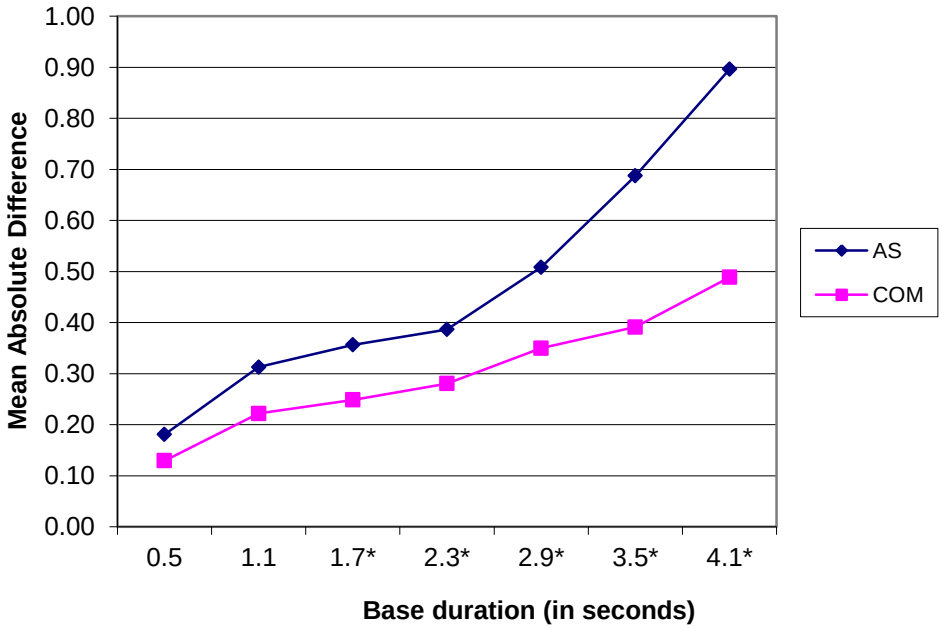
0.5	0.18 (0.11)	0.13 (0.08)
1.1	0.31 (0.21)	0.22 (0.17)
1.7	0.36 (0.19)	0.25 (0.12)
2.3	0.39 (0.16)	0.28 (0.13)
2.9	0.51 (0.20)	0.35 (0.18)
3.5	0.69 (0.35)	0.39 (0.22)
4.1	0.90 (0.44)	0.49 (0.29)

Figure Captions

Figure 1: The mean absolute difference between the base duration and reproduced duration at each base duration for the ASD and Comparison group.

Figure 2: The mean duration judgement ratio at each base duration for the ASD and Comparison group.

Figure 1: Top


1.00
0.90
0.80
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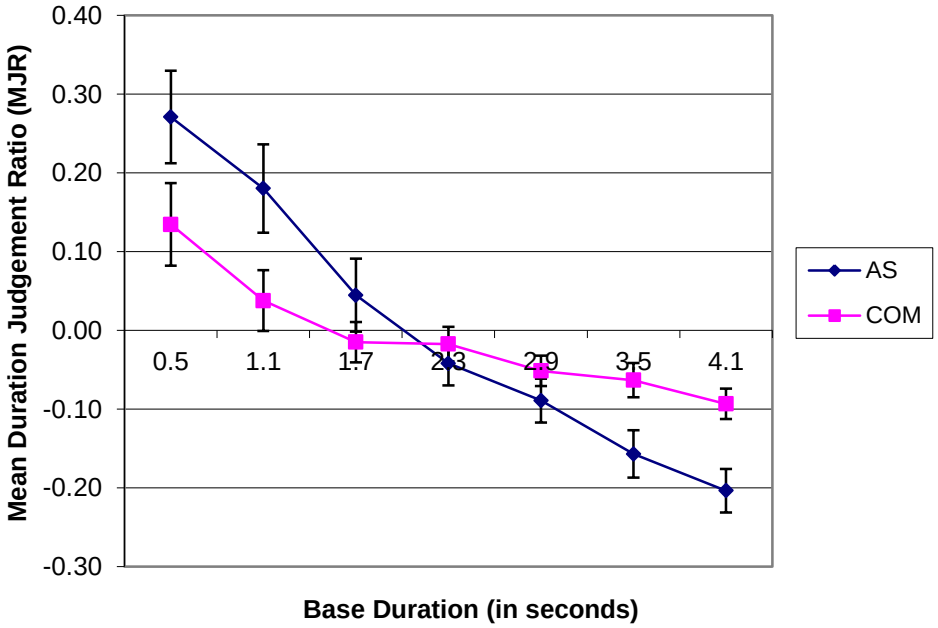
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Mean Absolute Difference
0.5
1.1
1.7*
2.3*
2.9*
3.5*
4.1*
Base duration (in seconds)
AS
COM

Figure 2: Top


0.40
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Mean Duration Judgement Ratio (MJR)
0.5
1.1
1.7
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4.1
Base Duration (in seconds)
AS
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