Spatial perspective taking is an embodied process, but not for everyone in the same way: Differences predicted by sex and social skills score.

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Abstract

We re-analysed the data from Kessler and Thomson's (2010) visuo-spatial perspective taking (VPT) experiments plus a previously unpublished pilot with respect to individual- and sex differences in embodied processing (defined as a body-posture congruence effect). We found that certain individuals called 'systemisers' (males/ low social skills) showed weaker embodiment than so-called 'embodiers' (females/ high social skills). Based on overall performance we conclude that 'systemisers' could either have difficulties with embodied processing or, alternatively, they could have a strategic advantage in selecting the appropriate level of embodiment or even a different mechanism altogether. In contrast, 'embodiers' could have an advantageous strategy of "deep" embodied processing reflecting their urge to empathise or, alternatively, less flexibility in fine-tuning the involvement of their bodily representations.

Introduction

One of the essential social features of humans is the ability to mentally adopt the perspective of others and understand their view of the world. Flavell et al (1986) proposed two levels of perspective taking. Level-1 is thought to reflect the understanding of *what* others can see, i.e. what lies within someone else's line of sight (i.e. which objects are visible, which occluded to the other person, e.g.: "You cannot see the bag because it is hidden behind the tree"). Level-2 perspective taking involves mentally adopting someone else's point of view and understanding *how* the world is represented from this virtual perspective ("From your perspective the flower appears to be to the right of the tree", compare Fig. 1). Level-2 is regarded as the more complex process of the two, which is evidenced by a later ontogenetic development, specific difficulties experienced by autistic children, and by phylogenetic differences. Level-1 develops around the age of 2 years and autistic children do not experience particular difficulties with this task (Baron-Cohen, 1989; Leslie & Frith, 1988). In contrast, level-2 develops around 4 to 5 years (Gzesh & Surber, 1985; Hamilton, Brindley & Frith, 2009), but not in children diagnosed with autism spectrum disorder (ASD), and level-2 performance is predicted by theory of mind (ToM) scores (Hamilton et al., 2009). Finally, primates seem capable of certain forms of level-1 but not at all of level-2 perspective taking (Tomasello et al., 2005). The latter conforms to their inability to perform simple ToM tasks (Call & Tomasello, 1999), which pose no problems for 5 year old (non-autistic) children.

With respect to Autism Spectrum Disorders or Conditions (ASD or ASC) the "extreme male brain" hypothesis has been suggested based on the more general distinction between a prototypical female and a prototypical male "brain" and associated psychological traits (Baron-Cohen, 2002; Baron-Cohen, Knickmeyer & Belmonte, 2005; Baron-Cohen et al., 2011). In this notion the female extreme is one of "empathising" while the male extreme is related to "systemising". 'Empathisers' are highly socially skilled and motivated, for instance, they can easily imagine what other people feel and what their intentions are, in other words they find it easy to adopt other people's social, emotional, and cognitive perspective. 'Systemisers' on the other hand are very good at non-social tasks that require a mathematical, logical or any other strictly systematic approach. Baron-Cohen and colleagues have investigated this distinction in depth and have repeatedly observed reliable sex differences with females being indeed the stronger 'empathisers' on average (Baron-Cohen & Wheelwright, 2004) and males the stronger 'systemisers' (Baron-Cohen et al., 2003), while no general intelligence differences were found. Further findings support the notion that ASC might be an extreme expression of a 'systemising' psychological profile (recently reviewed in Baron-Cohen et al., 2011). For the present report this notion suggests that 'empathisers' should be more inclined to really "put themselves into someone else's shoes" when adopting their perspective. 'Empathisers' would be expected to be predominantly female participants and/or those with high social and ToM skills.

In many languages spatial metaphors are employed to indicate the adoption of someone else's cognitive, emotional, or argumentative perspective (e.g. "Put yourself in my shoes", "From your point of view…" etc.), possibly suggesting a common origin rooted in spatial forms of mental alignment (Kessler & Rutherford, 2010; Kessler & Thomson, 2010). In our recent work (Kessler & Rutherford, 2010; Kessler & Thomson, 2010) we therefore focused on the visuo-spatial aspects of level-2 perspective taking (VPT-2) as a representative process for high-level perspective taking in general. As an example, imagine you would like to tell a friend that she has an eyelash on her left cheek, which would require determining 'left' and 'right' from our friend's perspective - independently from our own point of view. Or think of wayfinding instructions, where an instruction like "in front of the building turn left" assumes that the instructing and the instructed persons are mentally aligned into the same virtual perspective, i.e., that they both either mentally face the entrance from the outside or imagine coming out of the building. These examples point out the importance of VPT-2 in communication, e.g., for establishing a common frame of reference for understanding spatial localisations or more generally for establishing a shared view of the world (Frith & Frith, 2007). The latter has been identified as an essential stepping stone in human evolution (Frith & Frith, 2007).

Although apes do not seem to be capable of VPT-2 in the form of mentally adopting another perspective they are able and motivated to deliberately change their physical location for looking around obstacles and sharing what a human experimenter can see (Brauer, Call & Tomasello, 2005; Tomasello, Call & Hare, 1998). This reflects the basic understanding that a physical (apes) or mental effort (humans) is sometimes necessary in order to understand someone else's view of the world (Frith & Frith, 2007). This led us to hypothesise that VPT-2 could have originated from deliberate physical alignment of perspectives exhibited by apes (Kessler & Thomson, 2010). Specifically, we proposed that VPT-2 could be the mental simulation of a body rotation/translation into another person's perspective, which is line with work by others assuming that perspective rotations involve a 'mental rotation of the self' that is based on transformations of internal representations, observers possess of themselves (e.g. Arzy et al., 2006; e.g. Blanke et al., 2005; Farrell & Thomson, 1999; Kozhevnikov et al., 2006; May, 2004; Presson & Montello, 1994; Rieser, 1989).

In a series of four experiments (Kessler & Thomson, 2010) we indeed found substantial evidence that the transformation during VPT-2 strongly relies on the internal representation of the body (i.e., body schema). In particular we varied the participant's posture before every trial by turning their body either clockwise or anticlockwise, while the head remained still, gazing ahead at the monitor where the stimulus was displayed (cf. Fig. 1). The task was to adopt the indicated perspective/viewpoint around a table shown on the screen and judge whether the target object was left or right from that perspective (cf. Fig. 1). The target object could be either a gun or a flower on the table in front of the target perspective. The indicated perspective around the table varied across trials, inducing different degrees of angular disparity in a clockwise or anticlockwise direction. Hence, the participant's body posture (turned either clockwise or anticlockwise) could be congruent or incongruent with the direction of the indicated perspective, thus, with the direction of a mental rotation into that perspective. Our results consistently showed that a congruent posture speeded up processing compared to a neutral posture while an incongruent posture slowed it down (Expt. 1 and 2 in Kessler & Thomson, 2010). The posture effect was independent of whether we used an avatar or an empty chair to indicate the viewpoint to be adopted (Expt. 1 and 2 in Kessler & Thomson, 2010; cf. Fig. 1), hence, suggesting that the simulation of a body rotation is a process that is generally employed by typical participants for adopting another visuo-spatial perspective – equally for someone else's viewpoint (avatar) and for a new, imagined viewpoint for themselves (sitting in an empty chair).

Importantly, we did not observe a posture effect, and hence no simulation of a body rotation, for an equivalent mental object-rotation (OR) task (Expt. 3 in Kessler & Thomson, 2010), and in a separate study, also not for level-1 perspective taking: "I know that you cannot see the bag behind the tree" (Kessler & Rutherford, 2010). Overall we concluded that only VPT-2 is an embodied process in the sense of a self-initiated, deliberate simulation of a body rotation, supporting the general notion of endogenous motoric embodiment (Kessler & Rutherford, 2010; Kessler & Thomson, 2010). For the present report, however, we pursued the question if this mechanism was employed by everyone in the same way or whether there were systematic group- and individual differences. Based on the 'empathisers'-'systemisers' distinction and the "extreme male brain" hypothesis of ASC, our research questions were primarily directed at sex differences and the effect of autistic tendencies in the typical population. We investigated if different response patterns were evident within the typical adult population, for instance, in form of different strategies or hampered processing for VPT-2. While hampered processing would be reflected by longer response times and/or lower accuracy, different strategies would be reflected as a modulation (e.g. absence) of the posture effect. That is, some participants might have switched to a different process altogether that did not rely on the simulation of a body rotation. Evidence for such strategy selection was reported by Kozhevnikov et al. (2006) where some participants adopted a mental object-rotation strategy instead of a self-rotation when the task involved several objects and their spatial relationships. Individuals with autistic tendencies, i.e. 'systemisers', could be more inclined to switch to a different strategy (e.g. object-rotation) or they could be simply less efficient while using the same strategy, as they might adopt someone else's perspective less frequently and less spontaneously. These were equally probable outcomes in terms of individual differences and we set out to investigate their empirical substance.

Besides its social functions, visuo-spatial perspective taking (VPT-2) involves the manipulation of spatial representations that has been extensively studied in the context of the 'spatial updating' literature (e.g. Kozhevnikov & Hegarty, 2001; May, 2004; Rieser, 1989). When discussing individual and group differences of VPT-2 it is therefore important to take spatial abilities into consideration as well, in addition to sex differences in psychological traits like 'empathising' vs. 'systemising' (Baron-Cohen, 2002; Baron-Cohen et al., 2005). The two sexes have indeed been shown to differ in terms of spatial abilities (for a recent review see Wolbers & Hegarty, 2010). With respect to object-based spatial abilities males perform better on mental object rotation (OR) tasks (Linn & Petersen, 1985; Voyer, Voyer & Bryden, 1995), which, however, seem to be qualitatively different from perspective taking tasks and the default process of mental self-rotation as shown by Kessler and Thomson (2010, Expt. 3). In fact, VPT-2 proficiency has been reported to be the better predictor than OR for learning spatial layouts from navigational experience (Allen et al., 1996; Hegarty & Waller, 2004; Kozhevnikov et al., 2006; Shelton & Fields, 2006), most likely due to the need to continuously update self-object representations based on self-motion (Kozhevnikov et al., 2006; Wolbers & Hegarty, 2010) for generating a flexible survey-type layout representation (Coluccia & Louse, 2004; Montello et al., 1999). With respect to the latter, males tend to perform better than females as they rely more strongly on cardinal directions and metric information (Coluccia & Louse, 2004; Montello et al., 1999) and are less likely to lose track of their 'heading direction' than females, who report making stronger use of landmarks (Chai & Jacobs, 2009; Lawton, 1994) and rely more strongly on environmental cues for their bearing (Kelly et al., 2009). Hence, sex differences in the spatial aspects of VPT-2 processing were likely. Unfortunately, several of the studies on perspective taking as an individual predictor of navigation skills, do not report the sex distributions of their samples (Hegarty & Waller, 2004; Kozhevnikov et al., 2006). For this reason, our hypotheses related to sex differences regarding the spatial aspects of VPT-2 remained somewhat speculative at this stage.

As discussed, women have been shown to be more 'empathising' than males, while males are reliably more 'systemizing' (Baron-Cohen et al., 2005). In the context of VPT-2 this social dimension could play an important role with respect to the frequency of perspective taking in everyday life and in relation to the "depth" of embodying another perspective. That is, females and/or 'empathisers' could be more inclined to adopt someone else's perspective and do this more often in everyday situations, thus, becoming measurably more efficient in VPT-2 tasks (i.e. faster/ more accurate). This has indeed been observed in a recent study (Brunyé et al., under revision) that employed the Kessler and Rutherford (2010) stimuli, yet, without the posture manipulation, thus, limiting its imapct on the analysis conducted here (i.e., no 'embodiment' measure).

Alternatively, 'empathisers' could also adopt another perspective more deeply by "embodying" the other perspective more strongly. By this we mean that a possible expression of empathy could be that 'empathisers' fully align their own body schema with someone else in order to "feel" their perspective more comprehensively. For instance, women have been shown to be more proficient at reading facial expressions (for review Baron-Cohen, 2002) and in the context of social psychology it has been shown that the proficiency of interpreting facial expressions is related to the ability and tendency to mimic, or in other words, 'embody' that expression (Niedenthal et al., 2005; Niedenthal et al., 2001). We therefore hypothesise that females and generally 'empathisers' might have a stronger tendency to 'embody' another perspective by mentally aligning larger parts of their body schema with the other perspective. Hence, stronger 'embodiers' would show larger posture congruency effects, yet, at the same time might also be slower overall, because larger parts of the body schema would be transformed during mental rotation.

In addition to sex information we had also obtained scores on the Autism Spectrum Quotient (AQ, Baron-Cohen et al., 2001) from our participants and we focussed on those AQ subscales that had been previously reported to reflect social skills and ToM (Hoekstra et al., 2008; Stewart & Austin, 2009). Prime candidates were the AQ subscales "social skills" and "communication skills" and to a somewhat lesser degree "attention switching" and "imagination" (cf. Hoekstra et al., 2008; Stewart & Austin, 2009), but not "attention to detail" that has been consistently reported to be somewhat separate, defining an "attention to detail" factor of its own (Austin, 2005; Hoekstra et al., 2008; Hurst et al., 2007; Stewart & Austin, 2009).

Hypotheses and Generalisability

To summarise, there were several equally probable outcomes in terms of differences between participants with high vs. low social- and/or spatial skills that could also be reflected in sex differences: 1) Highly socially skilled participants such as ‘empathisers’, e.g. females, could have had more practice in perspective taking and therefore might be faster and more accurate than ‘systemisers’. 2) Alternatively, ‘empathisers’ and those more socially skilled, e.g. females, could be the stronger ‘embodiers’ leading to “deeper”, yet, also slower perspective transformations. Vice versa, males perform better on generating spatial layout representations that seem to rely on perspective-taking abilities, hence, males could be very skilled in employing perspective taking towards a ‘systemising’ end that would not necessitate “deep” empathy or embodiment. Males, however, also perform better in mental object rotation tasks, suggesting that 3) strong ‘systemisers’ might be more inclined to switch to an object-rotation strategy instead of perspective taking, which would be reflected by the absence of a posture congruency effect (cf. Kessler & Thomson, 2010, Expt., 3).

The primary focus of this report was to find individual and group differences with respect to embodied processing that might suggest different strategies for VPT-2. Towards this end we pooled and re-analysed the data from four VPT-2 experiments (N= 96) with respect to differences related to sex and social skills (AQ subscales). As shown in Figure 1, these experiments comprised the three perspective taking experiments from Kessler and Thomson (2010; Expts. 1, 2, and 4; in the following we will refer to this paper as K&T) plus a previously unpublished pilot. Anticipating one of the weaknesses of the current, merged dataset, the average AQ scores were lower than reported for the typical population (Baron-Cohen et al., 2001), allowing only limited conclusions regarding the whole of the population. While our analyses have to be regarded as exploratory, we did find plausible and intriguing patterns within this sample of participants with generally low autistic tendencies that are important to share with the scientific community for serving as cornerstone data and for inspiring new research questions.

Methods

Comparisons across four Experiments

Figure 1 shows the four Experiments that we employed for our combined analysis. The task was always to adopt a target perspective, indicated by an avatar or an empty chair (Expt., 2 in K&T), and to make left/right judgment from that perspective by means of spatially mapped button presses (see Fig. 1 for details). The conditions they had in common were 4 angular disparities (40°, 80°, 120°, 160° clockwise and anticlockwise) and 2 body postures (congruent vs. incongruent to the direction of mental rotation), which formed the core design for our combined analysis. Other manipulations like the presence of an avatar (Fig.1, A; Expt. 1 in K&T) vs. an empty chair (Fig.1, B; Expt. 2 in K&T), the posture of the avatar (Fig.1, C; Expt. 4 in K&T), and the exact location of the target objects (Fig. 1, D; unpublished Pilot) varied across the four included experiments and were disregarded in the present analysis. To enhance comparability across experiments (e.g. Faust et al., 1999) we calculated z-scores for each experiment separately by subtracting the grand average and dividing by the standard deviation of that experiment for each participant's RT score in each condition. For indexing a particular experiment throughout the manuscript we will refer to the Panel in Figure 1 that shows that Experiment (i.e. Expts. A-D).

********** Figure 1 about here **********

Participants

In all four experiments participants were volunteers, right-handed, had normal or corrected-to-normal vision, were naive with respect to the purpose of the study, and received payment or course credit for participation. 51 females and 45 males took part in these four Experiments. AQ scores (mean = 14.1; median = 14; stdev = 5.7) were below population average (mean = 17.6; stdev = 6.4, cf. Baron-Cohen et al., 2001) and there was a slight difference between sexes (females = 13; males = 15) that mimicked the population difference (females = 16.4; males = 18.6), yet without reaching significance ($t(94) = 1.48$; $p = .6$).

Stimuli and Design

Visual stimuli in Expts. A, B, and D employed angular disparities of 0°, 40°, 80°, 120°, or 160°, clockwise or counterclockwise (Figure 1A), while in Expt. C, 0° had been omitted. For the analysis here we only considered angular disparities of 40° and above. Expt. B did not employ an avatar but an empty chair (cf. Fig. 1), while all other features were identical to Expt. A (see K&T for details). All pictures were taken from a vertical angle of 65°. Stimuli were coloured bitmaps with a resolution of 1024 by 768 pixels corresponding to the graphic card settings during the experiment. Viewing distance to a 19" monitor was 65 cm and a chin rest was employed to ensure constancy in all four Experiments.

In all four Expts. the body posture of the participants was varied randomly across trials (cf. Figure 1, Panel D). The body in relation to the head/face/gaze direction (which remained straight towards the monitor) could be turned clockwise or counterclockwise, hence, being congruent or incongruent to the direction of mental self-rotation in all four Expts. In Expts. A and B but not in C and D there was also a neutral condition where the body remained straight, however, the major embodiment effects reported in K&T (also Kessler & Rutherford, 2010) were revealed as the difference between an incongruent and a congruent posture at high angles (120° and 160°) so we only included the congruent and incongruent postures in the present analysis (for details regarding the neutral conditions we refer to K&T, Expts. 1, 2). Please note that in all Expts. participants also moved the response device (mouse) together with their body (cf Figure 1). Marks on the table indicated exactly were to place the mouse to ensure a constant angle of ±60° (clockwise/counterclockwise) between body and head across trials. In Expt. C the posture of the avatar could also change, being either the same or different to the posture of the participant. Here we collapsed across these two possibilities (for details of the original effects see K&T, Expt. 4).

Procedure

In all four Expts the trial procedure was the same. Each trial started with the posture instruction (cf. Figure 1). When participants had assumed the correct posture they pressed both mouse buttons to proceed to the next step, which was the target instruction. A picture of the target object (gun or flower) was shown together with the respective noun. Participants pressed again both mouse buttons when they felt ready to start the actual task. A fixation cross was shown for 500 ms and was automatically replaced by the experimental stimulus. Participants were instructed to respond as quickly and as accurately as possible. Audio-visual feedback was then provided reflecting accuracy of the response. On every trial a flower and a gun were lying in front of the avatar (Expts A-C) or were placed in the hands of the avatar (Expt. D) and participants had to press the corresponding mouse button (left or right) for the side (left or right) on which the target was positioned from the avatar's viewpoint. In Figure 1A this would require pressing the right button for the flower or the left button for the gun (the other way around in Panel B). The relative positions of the gun and the flower (left/right vs. right/left) as well as the target object (gun vs. flower) were balanced across trials in all Expts. There was a total of 324 trials in Expts A and B, 256 in C, and 216 in D.

Variables for multiple linear regressions

The original four experiments employed factorial designs that specifically manipulated certain variables (angular disparity, posture) to test their effect on response times (RT). These original studies were not primarily intended to reveal individual or even group differences as reflected by their small number of participants (24 per experiment). By pulling together four datasets we are in the position to test for sex differences and the predictive potential of AQ scores (and AQ subscales). One step for increasing the compatibility of the datasets was to generate z-scores from the original RT data for each individual and each cell of the design based on the average and the standard deviation of that particular experiment. In order to constrain the design of a final general linear model analysis (GLM) we included a first step where we employed multiple linear regressions (MLR) to predict variables of interest based on their mutual relationships, on sex and on AQ scores. The most important variable was an individual measure of 'embodiment', but we also extracted individual measures of basic speed ('offset') and speed increase ('slope').

A measure of embodiment

The major aim of this combined analysis was to identify individual- and group-specific patterns of embodied processing during spatial perspective taking. In our previous research we have repeatedly shown and explained that the mental simulation of a self- and body-rotation is predominantly employed at angles above 90° and, thus, embodiment effects are most clearly observed at these angles (Kessler & Rutherford, 2010; Kessler & Thomson, 2010). Below 90° left-right tasks can be solved – in theory – by a visual discrimination procedure and does not require mental self-rotation (for details see Kessler, 2000; Kessler & Thomson, 2010). We therefore calculated the average difference between incongruent and congruent posture at 120° and 160° degrees as an individual measure for the amount of embodied processing and used it in multiple linear regression analyses (embodiment = ((incongruent-congruent)@120°+(incongruent-congruent)@160°)/2). Note that the calculation is based on RT z-scores. At 160° and 120° these are likely to be positive values in contrast to 80° and 40° that would be predominantly negative, thus, achieving an overall average of 0. The majority of participants (81 out of 96) showed an embodiment effect, hence, subtracting congruent from incongruent posture revealed mostly positive values as well. Therefore, values for the 'embodiment' measure were predominantly positive and did not average to 0 (e.g. Fig. 2, B).

As described in the Introduction (see *Hypotheses*) we propose that the individual embodiment measure reflects the proportion of the body schema that is mentally transformed during VPT-2 by that individual. This is clearly tentative at this stage but provides an operational definition. Accordingly, individuals that strongly involve their body schema in mental perspective transformations reveal "more deeply" or "more strongly" embodied processing, whereas individuals with low embodiment measures might be better at ‘disembodying’ themselves, transforming a reduced proportion of their body schema (e.g. only the head not the whole body posture). Individuals who do not show any posture effect at all (0 or negative embodiment values) might even employ a different strategy altogether – e.g. mental object rotation instead of self-rotation (cf. Kozhevnikov et al, 2006; see discussion of Expt. 3 in K&T). We expected ‘empathisers’ (females, low AQ scorers especially with respect to social skills and ToM) to show higher embodiment measures as they might embody another perspective “more deeply” than ‘systemizers’ (males, high AQ scorers especially with respect to social skills and ToM).

Speed measures: Slope and offset

Other variables of interest on which individuals and sexes might differ and which could aid in predicting an individual’s embodiment measure are related to processing speed. We extracted two different measures for each individual. Firstly we calculated the ‘slope’ as a measure for the RT increase across angles. Congruent to the literature on mental object rotation (e.g. Cohen & Kubovy, 1993) we extracted the b-values from the individual linear regressions, where the b-value indicate the slope of the linear relationship between angle and RTs. Z-scores were then calculated from these b-values in relation to the average and standard deviation of that particular experiment.

Note that the higher the b is, the steeper the slope, i.e. the slower RTs become with increasing angle. This is important because a stronger RT increase could either indicate larger difficulties with VPT-2 (cf. hypothesis 1, see Introduction) or it could be an indication for “more deeply” embodied processing (cf. hypothesis 2). The former has indeed been recently shown by our group (Brunyé et al., under revision). However, in that study we did not employ a measure of embodiment so we cannot conclude if and how this measure was modulated by AQ and sex. As described in the Introduction 'empathisers' are likely to show stronger embodiment, which is proposed to reflect the proportion of body schema transformed during mental rotation. If that was the case than slopes might increase more strongly the more deeply embodied the transformation was - due to larger parts of the body schema being transformed (cf. hypothesis 2). Hence, 'empathisers' (females, low AQ scorers) could actually reveal larger slopes together with larger embodiment values in the present sample, where 96% of the participants were within 1std. dev of the population mean (scores < 24 cf. Baron-Cohen et al., 2001). In conclusion, 'slope' was expected to be a significant predictor for the embodiment measure (and vice versa), but the direction of the relationship (positive or negative) was uncertain at this stage (see *Hypotheses*).

In addition to slope we employed a measure for baseline speed of target selection without the additional costs of mental transformation. In the mental object rotation literature the offset of the individual linear regressions is used as such a measure, but for theoretical reasons we could not follow that procedure here. For mental object rotation RTs increase monotonically from 0 onwards. For mental self-rotation, however, it has been repeatedly shown that RTs only begin their increase at around 60°-90° angular disparity (Keehner et al., 2006; Kessler & Thomson, 2010; Kozhevnikov & Hegarty, 2001; Michelon & Zacks, 2006), supporting the notion that mental self-rotation is only engaged at higher angles (Kessler, 2000; Kessler & Rutherford, 2010; Kessler & Thomson, 2010). Therefore we employed average RTs at 40° as a measure for 'offset'.

AQ and AQ subscales

As discussed earlier, the subscales of the AQ may not be equally important to the issue of embodied processing during perspective taking. Although some of our recent findings (Brunyé et al, under revision) suggest a relationship between total AQ score and 'slope' of VPT-2 (AQ scores ranged from 3-29 mean = 15.9, SD = 5.6), the average AQ in the present dataset was somewhat lower (mean = 14.1; stdev = 5.7). In order to confirm the importance of some AQ subscales over others (e.g. "social skills" > "attention to detail") we entered all subscales into a MLR model to predict 'embodiment'. Significant predictors would then we be considered in further analysis, i.e. GLM. The subscales are: "social skills" (AQss), "attentional switching" (AQas), "attention to detail" (AQad), "communication" (AQcom); "imagination" (AQimg). As described in the Introduction, AQss and AQcom possibly together with AQas and AQim were regarded as the best candidates for significant predictors of empathising perspective taking - with low scorers expected to show stronger 'embodiment'.

Results and Discussion

Multiple Linear Regression (MLR) analyses

Predicting Embodiment based on AQ subscales

One of the main aims of this report was to understand which variables would allow us to predict the amount of embodiment individuals employ during perspective taking. The theoretical consideration behind this was that individuals with high social skills, so-called 'empathisers' would embody another perspective more deeply, reflecting their tendency to align themselves more profoundly with other people. As discussed, the subscales of the AQ might contribute to varying extents to this particular variable.

Therefore we first conducted a multiple linear regression that included the AQ subscale scores as predictors and the 'embodiment' measure as criterion (see previous Section for calculation details). This allowed us to identify important predictors and to test for multicolinearity between the AQ subscales[1]. Table 1A shows hat only 'social skills' (AQss) revealed a significant negative relationship with 'embodiment' (negative b-value), where low scorers (i.e. high social skills) showed higher embodiment. Multicolinearity was not an issue (in Table 1, top all 'tolerance' values > .2, cf. Menard, 1995), hence, it was unlikely that an important predictor was missed.

********** Table 1 about here **********

********** Figure 2 about here **********

In a subsequent step we included the other variables we had discussed in the previous Section as potential predictors of 'embodiment' together with AQss into an MLR: 'sex', 'slope', and 'offset'. The results for the model are shown in Table 1B indicating that all variables besides 'offset' significantly contributed towards predicting 'embodiment'. In a further MLR analysis we replaced AQss by total AQ score, but AQ did not reach significance ($p = .28$), suggesting that AQss was indeed the better predictor for 'embodiment' in this particular sample of participants.

The final model (sex, slope, and AQss), shown in Figure 2, revealed that individuals with steeper slopes were likely to be stronger 'embodiers' than those with small

[1] Studies that explored the AQ substructure by means of factor analyses (see Introduction) had shown that several AQ subscale, e.g. "social skills" and "communication" were loading highly on the same factors, thus, it was important to understand the relation between the AQ subscales and 'embodiment' first, before other variables were added into the equation.

slopes and that individuals with high social skills (low AQss scores) as well as female participants were the stronger ‘embodiers’ than high AQss scorers and males, respectively. Figure 2, A shows the relationship between the values predicted by the model and the observed ‘embodiment’ measures. One case seemed to be an outlier (case 80, circled), yet, its Cook’s distance of 0.37 (< 1) indicated that this case did not significantly distort the model (cf. Cook & Weisberg, 1982). As can be seen in Figure 2, B (correlations), this particular participant was female, had the steepest slope out of everyone (3.96), and the lowest possible AQss score (0) reflecting high social skills. This participant also happened to have the strongest ‘embodiment’ measure out of everyone (2.02), which was somewhat underestimated by the model, but which is in agreement with our theoretical considerations.

Only AQss turned out be a significant predictor for the strength of embodied processing during VPT-2 in our sample. Initially, AQcom had been regarded as a prime candidate as well (see Introduction and Methods). However, our data did not support this expectation, which is likely due to the limited range of AQ scores in the present sample. Overall, the MLR results suggested that ‘sex’ and ‘AQss’ should be included into the final general linear model analysis (GLM) that would allow us to understand in detail the effects of interactions between the dependent variables on response times.

General Linear Model (GLM) analyses

Based on the MLR results we extended our basic design consisting of the within-subject factors ‘posture’ (incongruent, congruent) and angle (40°, 80°, 120°, 160°), by adding the between-subjects factor sex (female, male), and the continuous predictor

AQss (score on the “social skills” subscale of the AQ). The dependent measures were RTs (z-scores). According to Mauchly’s test (p<.05) sphericity could not be assumed for ‘angle’ and ‘angle x posture’, hence, we report Greenhouse-Geiser corrected results. ‘Angle’ and ‘posture’ revealed significant main effects (angle: F(1.43, 133.36)=113; p<.0001; posture: F(1, 93)=69.6; p<.0001) and a significant interaction (F(2.66, 246.8)=11.08; p<.0001) confirming our previous results with separate analyses for these four experiments (K&T; for a replication see Kessler & Rutherford, 2010). Regarding between-subjects factors ‘AQss’ significantly interacted with posture (F(1, 93)=7.7; p<.007), confirming ‘AQss’ as a significant predictor of ‘embodiment’ as shown in Figure 2 (note, however, that the latter represented the posture effects at 120° and 160° only). Sex played a substantial role as a main effect (F(1, 93)=6.5; p=.012) and by significantly interacting with posture (F(1, 93)=12.3; p<.001), with angle (F(1.434, 133.4)= 6.5, p=.006), and with both, posture and angle (F(2.66, 247.4)=3.4; p=.024), as shown in Figure 3, Panel A. When included into the model, the interaction term between ‘AQss’ and ‘sex’ did not reach significance (p=.8) and neither did any of the multiple interactions between ‘AQss’, ‘sex’ and any of the other factors (all p > .3), suggesting independent contributions by sex and AQss.

********** Figure 3 about here **********

When investigating in more detail the influence of sex on the interaction between posture and angle (Fig. 3) we found in agreement with both 2-way interactions (sex by posture and sex by angle) that females generally showed a stronger posture effect, but were also slower - particularly at high angles (120° and 160°). Secondly, we found that the two sexes only significantly differed regarding their posture effects at 120° and 160°. In addition, males showed a significant posture effect at 120° ($p = .002$) but not quite at 160° ($p = .06$). While this is clearly speculative, it could suggest that males are more likely to adopt a different strategy on some trials, particularly at 160°, which diminishes their posture effect. This is further corroborated by three male participants, who showed a drop in RTs at 160° compared to 120°, clearly suggesting a different strategy to solve the task (for further details see General Discussion: Individual strategies and patterns).

In general the two sexes differed significantly in their speed for solving the tasks, although there was no significant difference regarding AQ and AQss in our sample. We found several pieces of evidence that could indicate that males are more inclined to employ a different strategy while females are generally inclined to rotate large parts of their body schema into another perspective, thus embodying that perspective more comprehensively than males. Another piece of evidence that could support this interpretation are accuracy data. We employed the identical procedure as for RT data, transforming the individual percent-correct rates (ACC) into z-scores (see Methods). The same GLM design as for RTs was used and did not reveal significant main effects of 'sex' ($p=.96$) or AQss ($p=.76$), but significant main effects of 'posture' ($F(1, 93)=8.4$; $p=.005$), 'angle' ($F(2.22, 206.4)=16.01$; $p<.0001$) and a statistical trend for an interaction between 'sex', 'posture', and 'angle' ($F(2.67, 248.7)=2.22$; $p=.09$). As can be seen in Figure 3, Panel B, males revealed a quite different pattern at 160° compared to females. While females showed significant posture effects at 120° as well as 160° (120°: $p <.001$; 160°: $p = .015$), for males, congruent and incongruent postures differed at 120° ($p < .001$) but not at 160° ($p = .56$), which was confirmed by a significant interaction of ‘posture’ (congruent vs incongruent) x ‘angle‘ (160° vs 120°) for males only (F(1, 44)=7.6; p=.008).

Together with the RT pattern, the ACC results corroborate the notion that males might be more inclined to adopt other strategies to solve VPT-2 tasks especially at 160°, where the avatar (or chair) was almost in an opposed position. Possibly, on some trials males switched to a rule-based strategy, deciding that their “left” was the target perspective’s “right” and vice-versa. The RT pattern of three males further supports this notion as their RTs decreased from 120° to 160° (for details see General Discussion: Individual strategies and patterns).

General Discussion

First of all it is important to point out that we had only access to a very limited number of individual variables, hence, it is important to keep in mind that measures such as dissociative tendencies, delusions, internalization, mindfulness etc. could be essential for fully explaining embodied processing and strategy choice in VPT-2 tasks. The significant predictors of ‘embodiment’ we found in the MLR analysis conducted here, were the ‘slope’ of processing speed as it increased across angles, ‘sex’, and ‘AQss’ (‘social skills’ subscale of the AQ). The ‘embodiment’ measure was based on theoretical considerations and conclusions derived from previous work (Keehner et al., 2006; Kessler & Thomson, 2010; Kozhevnikov & Hegarty, 2001; Michelon & Zacks, 2006; Zwickel et al., 2011), suggesting that mental self-rotation in form of a body-movement simulation was only reliably engaged at angles higher than 90°. The ‘embodiment’ measure was obtained by subtracting a congruent from an incongruent posture at 120° and 160° angular disparity and by calculating the average of the differences across the two angles (see Methods for details). MLR analysis revealed that individuals with better social skills (low AQss score), steeper RT slopes, and female participants showed higher ‘embodiment’ measures. This general pattern was substantiated in a GLM analysis, where female participants were the stronger ‘embodiers’ than males, while also revealing a stronger increase in RTs across angles (cf. Figure 3). The significance of social skills (AQss) was also confirmed in the GLM analysis: stronger ‘embodiers’ were those with higher social skills.

At the outset of this analysis (see Introduction and Methods) we proposed three hypotheses: 1) ‘Empathisers’ (females, low AQss scoreres) could be more inclined to adopt someone else’s perspective and do this more often in everyday situations, thus, becoming more proficient in general and in our VPT-2 task in particular. 2) ‘Empathisers’ could adopt another perspective more deeply and “embody” the other perspective more strongly, leading to a larger posture effect but also to slower overall processing. 3) ‘Systemisers’ might switch to alternative strategies (e.g. object rotation ‘OR’, or rule-based), thus revealing no embodiment effect. According to hypothesis (2) the individual embodiment measure reflects the proportion of the body schema that is mentally transformed during VPT-2 by that individual. Accordingly, individuals that strongly involve their body schema in mental perspective transformations reveal “more deeply” or “more strongly” embodied processing, whereas individuals with low embodiment measures might be better at ‘disembodying’ themselves, transforming a reduced proportion of their body schema (e.g. only the head not the whole body posture) or might even employ a different strategy altogether – e.g. mental object rotation instead of self-rotation (cf. hypothesis 3). The 2nd hypothesis seems to be strongly supported by our findings, especially with respect to female participants, who showed larger embodiment as well as larger slopes (cf. MLR and GLM interactions between sex x posture; sex x angle; sex x posture x angle). Social skills (AQss score) did not differ between males and females while revealing an interaction with posture but not with angular disparities. This could suggest that the relationship between slope and embodiment might be predominantly a sex effect, while social skills predict the use of embodied processing, yet, without necessarily increasing RTs at high angles (slope) at the same time. Practice might overcome the higher costs for transforming larger parts of the body schema. The latter provides some support for hypothesis (1).

We have to interpret our findings with caution due to the limited range of AQ scores obtained in our sample, where the high, subclinical range was underrepresented (for both sexes). In concordance with hypothesis (1), truly strong 'systemisers' (high AQss and total AQ score) might actually reveal an increase in slope due to a lack of practice in adopting other perspectives, while, at the same time also a lack of embodiment, as their perspective-taking could be shallow, involving only little of the body schema. Alternatively, 'systemisers' might switch to an 'OR' strategy, showing no posture effect at all. Hence, a dissociation between 'slope' and 'embodiment' could be observed in high AQ scorers: while slopes might increase, embodiment might decrease (unlike the effects obtained here for the female group). Recent data from 140 participants tested by Brunyé et al (under revision) on a VPT-2 task (identical to Expt. 1 in Kessler & Rutherford, 2010) indeed revealed an increase in 'slopes' with increasing AQ scores, while the average AQ score was somewhat higher than in the sample considered here. At the same time female participants in the Brunyé et al sample had lower AQ scores than males but also a 15% larger slope on average congruent to the strong sex effects reported here. This suggests a non-linear relationship between AQ and slope depending on sex. However, since an independent measure of embodiment was not obtained in the Brunyé et al. study, the exact impact of this non-linear relationship on embodied processing of perspective rotations cannot be determined.

Highly Explorative: Some Individual Strategies and Patterns

In this Section we explore qualitatively different response patterns within our sample that might reflect the use of different strategies. Firstly, we examined how many participants might have switched away from a mental self-rotation strategy to a rule-based strategy at 160°. At this particular angle the target perspective is almost opposite of the participants, so one could easily and quickly transform the egocentric left and right into a reversed left and right (i.e. “my left is their right”). Such a change in strategy would be most clearly reflected by a drop in response time from 120° to 160° degrees. We observed such a drop in 3 out of our 96 participants. All of them were male and while they did not score overall highly on the AQ, all three where relative top-scorers (≥ 5) on the “attention to detail” AQ subscale. Secondly, we examined which participants did not show an embodiment effect at all. 15 out of 96 participants did not show a response time advantage for a congruent posture neither at 120° nor at 160° angular disparity. Out of these 15, 12 were male and 9 had scores in the top 50% of AQ scores in males. Of the 3 females 2 scored in the top 50% of AQ scores in females. Overall this provides some support for hypothesis 3 (see *Hypotheses*) suggesting that predominantly ‘systemisers’ are inclined to switch to strategies other than embodied perspective taking (e.g. OR and rule-based) to solve the VPT-2 task at hand (see Introduction).

Reflections on Embodiment and Spatial Cognition

In this Section we will address some of the broader questions that have been raised as a motivation for this Special Issue:

- Are embodied processes in spatial cognition automatic or obligatory?
- Can they be strategically or flexibly applied?
- Is there a strict, one-to-one mapping between the physical body and mental representations of the body and its action space?

Level-2 perspective taking (VPT-2) is most often described as a deliberate process that people can choose to perform or not, which depends on the context of the situation, specifically with respect to the benefit of such an effortful process for the social interaction, e.g. during communication (for reviews see Grabowski & Miller, 2000; Kessler & Rutherford, 2010; Levelt, 1996). However, Zwickel at al (2011) reported interference effects between the perspective of a stimulus that is perceived as an animated cognitive agent and the egocentric perspective during left/right judgements, suggesting an automatic process that takes others' perspectives into consideration. This effect not only questions the assumption of conscious deliberation in choosing to perform a perspective transformation but it was also demonstrated in autistic participants, thus challenging the view that social skills are indispensible for performing mental rotations of perspective. This conforms to some extend to our finding that males are the weaker 'embodiers' than females, while showing faster responses at the same time (with comparable accuracy). This indicates that there can be a dissociation between the proficiency in achieving a VPT-2 outcome and the use of deliberate, effortful, and embodied strategies.

Nevertheless, our findings strongly suggest that mental self-rotation in form of a movement simulation is the default mechanism for VPT-2 in the vast majority of our participants (84 %). It could, however, be that this process is employed automatically, i.e. without deciding in detail which strategy to use for VPT-2 (only the "if"). So while the decision of engaging perspective-taking can be a deliberate and conscious process, the mental simulation of a body rotation that subserves VPT-2 (Kessler & Thomson, 2010), could be automatic or even obligatory. However, as described in the previous Section, a small but not negligible number of participants chose other strategies and possibly engaged mechanisms of object rotation (rotating the table and the objects towards them and not themselves into the other viewpoint) orrule-based at the highest angular disparity (e.g. "my left is their right" at 160°). We therefore must conclude that the embodied mechanism of VPT-2 is not obligatory - since some individuals chose different mechanisms - while at the same time it seems to be automatic (i.e. default) in the large majority of the sample. Individuals who choose not to employ this default mechanism tend to be male and tend to possess less social skills than males who engage the embodied mechanism.

However, this leaves the question unanswered whether weak 'embodiers' really employ a different strategy like mental object-rotation or whether they are simply better at "disembodying" themselves, i.e. by rotating only a very limited part of the body schema, just sufficient to perform the task. The latter is supported by the generally smaller embodiment effects in the male group. 'Embodiers' in contrast, could have a generally stronger automatic or deliberate tendency to engage in movement simulation across a wide range of tasks that require mental transformations of spatial viewpoints. This could reflect a deeper processing level of the mentally simulated perspective as a particular expression of empathy in congruence with a social goal, which could have advantages for further social processing (for a similar notion, see Niedenthal et al., 2005). Alternatively, 'embodiers' could be less able to suppress or control embodied processing in relation to the task requirements at hand.

In conclusion, we propose that 'systemisers' and 'empathisers' might define the VPT-2 task in two completely different ways. While 'empathisers' might define it as a social task, transforming large parts of their body schema into the other perspective as a deliberate or automatic expression of empathy, 'systemisers' might define it as a purely spatial task. The latter might allow for more strategic flexibility, for instance, by transforming a reduced body schema or by employing an object rotation strategy. This could lead to a mix of strategies across participants and across trials, for which we found evidence in the male group. Specifically at 160° males showed reduced embodied processing in RT and ACC data that could reflect a switch to object rotation (mentally turning the table towards them), or a rule-based strategy (e.g. "my left is their right"). Our results are particularly interesting because of the low and comparable AQ and AQss scores across sexes. Even within a sample of socially skilled individuals sex differences were apparent and males and females might have approached our somewhat artificial VPT-2 paradigm from two different angles, i.e., females more empathically from a social- and males more systematically from a spatial angle, possibly resulting in more strategic flexibility in the male group.

Finally, an intriguing question has been raised regarding the strength of the body-to-mind mapping. The differences we have observed between strong and weak 'embodiers' seem to suggest that different individuals transform different proportions of their body schema during mental self-rotation. Therefore, one of the dimensions on which individuals could differ is the amount of mapping between the physical body and its mental representation during spatial viewpoint transformations: Some individuals, here called 'embodiers' are much closer to a one-to-one mapping than others, who may be called 'disembodiers'. Mechanistically, the amount of mapping could be a consequence of individual personality and strategy selection and therefore reflect the individual depth of empathic processing in concordance with a social understanding of the task (e.g. females, 'empathisers'), or the individual ability for top-down control of body schema involvement in relation to a systematic understanding of spatial task requirements (e.g. males, 'systemisers').

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Table 1: The top half shows the results for the multiple linear regression (MLR) model with 'embodiment' as criterion and with all AQ subscales included as predictors (AQss = social skills; AQas = attention switching; AQad = attention to detail; AQcom = communication; AQimg = imagination). The bottom half shows the results for the final MLR model for 'embodiment'. Note that measures of embodiment were calculated as the individual average difference between incongruent and congruent posture at 120° and 160° degrees. Further explanations in the text.

Regression for Dependent Variable 'Embodiment' R= .34, R²= .12, Adjusted R²= .07, F(5,90)=2.4, p<.045, Std.Error of estimate: .39								
N=96	**b***	**Std.Err.**	**b**	**Std.Err.**	**t(91)**	**p**	**Part Corr**	**Tolerance**
Intercept			0.36	0.12	2.88	0.00		
AQss	-0.26	0.12	-0.06	0.03	-2.17	0.03	-0.223255	0.688763
AQas	-0.10	0.11	-0.02	0.02	-0.89	0.37	-0.093645	0.798091
AQad	0.12	0.10	0.02	0.02	1.21	0.23	0.126923	0.991504
AQcom	0.19	0.12	0.05	0.03	1.59	0.11	0.165622	0.720705
AQimg	-0.12	0.11	-0.03	0.03	-1.09	0.28	-0.114160	0.769985

Regression for Dependent Variable 'Embodiment' R= .66, R²= .44, Adjusted R²= .41, F(4,91)=17.7, p<.0001, Std.Error of estimate: .31								
N=96	**b***	**Std.Err.**	**b**	**Std.Err.**	**t(91)**	**p**	**Part Corr**	**Tolerance**
Intercept			0.33	0.07	4.90	0.00		
SEX	0.21	0.08	0.17	0.07	2.58	0.01	0.261252	0.915764
Offset	0.07	0.08	0.05	0.06	0.86	0.39	0.089465	0.886551
Slope	0.49	0.09	0.20	0.03	5.80	0.00	0.519435	0.852627
AQss	-0.18	0.08	-0.04	0.02	-2.30	0.02	-0.234620	0.981562

Figure Captions

Figure 1: The four experiments that were included in the combined analysis reported here. Panels A-C show stimuli (originally in colour) and major results from Experiments 1, 2, and 4 in K&T (Expt.3 in K&T tested object rotation and was not included in the present analysis). Panel D shows a previously unpublished pilot experiment where the potential target objects (gun and flower) were not positioned on the table but in the hands of the avatar. The task was always to indicate if the target object (either gun or flower, randomised across trials) was left or right from the avatar's/chair's perspective. Panel E shows the two possible postures of the participants (clockwise and anticlockwise rotation of the body) that were employed in all four Experiments. In relation to the clockwise or anticlockwise position of the avatar/chair around the table these postures could be defined as being either congruent or incongruent with the direction of mental self-rotation. In sum, all four experiments had the following conditions in common: 2 posture conditions (congruent vs. incongruent) and 4 angular disparities (40°, 80°, 120°, 160°; collapsed across clockwise and anticlockwise disparities). Further explanations in the text.

Figure 2: Panel A, scatter plot of observed values of 'embodiment' (y-axis) vs. values predicted by the MLR model (x-axis). An individual measure of embodiment was calculated as the average difference between incongruent and congruent posture at 120° and 160° degrees (compare Fig. 1). The model included 'sex', 'slope', and 'AQss' as predictors and the correlations of each predictor (x-axes) with 'embodiment' (y-axis) are shown below, in Panel B. For the predictors frequency distributions are shown above the correlation plots, whereas frequency distribution for 'embodiment' is shown to the right. Case nr 80 is circled in all scatterplots as a

potential outlier, yet, Cook's distance did not exceed 1 suggesting that case 80 did not significantly distort the model (cf. Cook & Weisberg, 1982). Furthermore, this participant is female, has the steepest slope of everyone (3.96), and is highly socially skilled (AQss=0), which conforms to our theoretical considerations. Further explanations in the text.

Figure 3: Panel A shows response times (RT) graphs for the ANOVA with posture and angular disparity as within factors and with sex as between factor. Panel B shows the corresponding percent-correct (ACC) graphs. Error bars denote the standard error of the mean. Further explanations in the text.

Figure 1

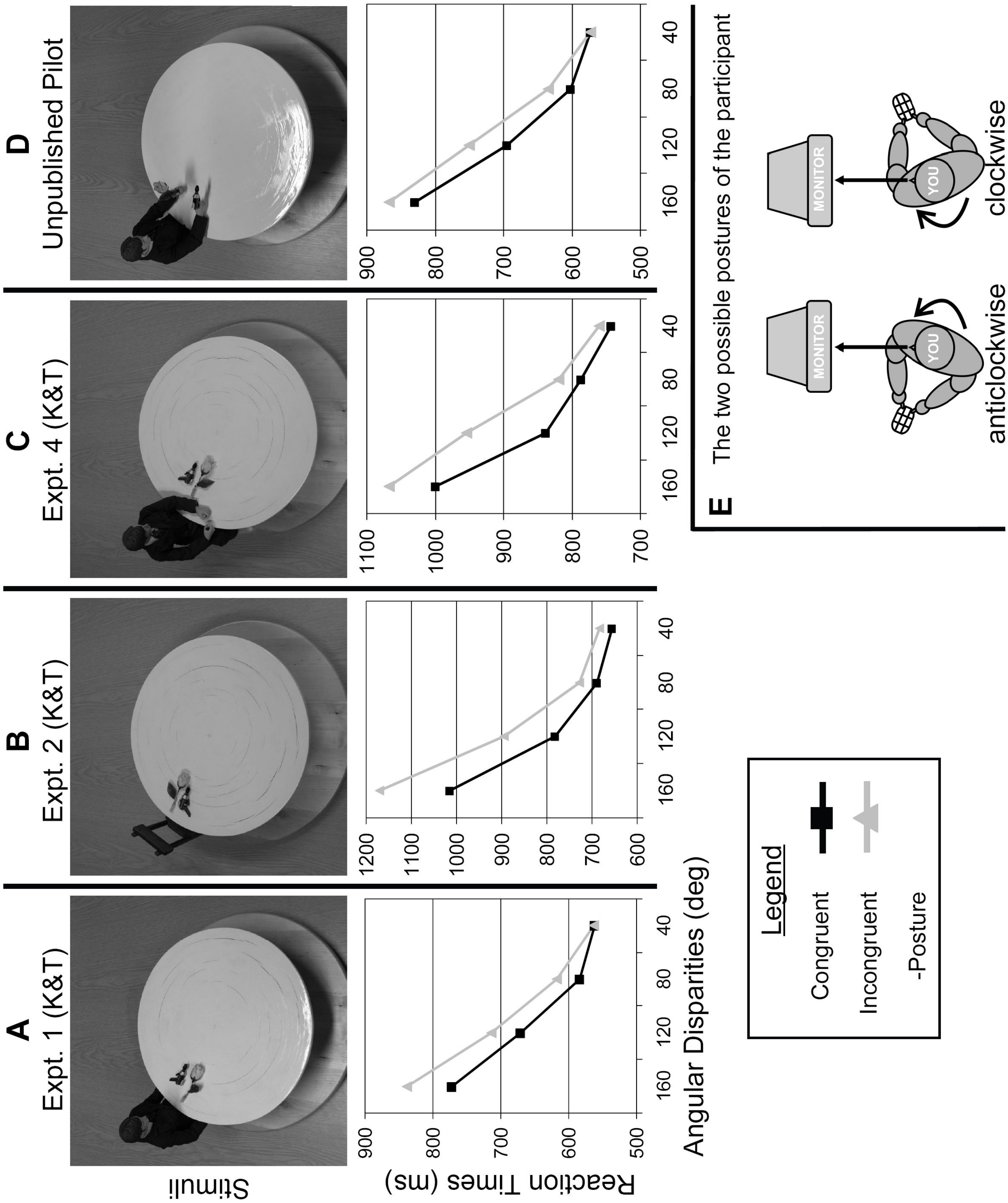

A
Expt. 1 (K&T)
B
Expt. 2 (K&T)
C
Expt. 4 (K&T)
D
Unpublished Pilot
Stimuli
Reaction Times (ms)
Angular Disparities (deg)
Legend
Congruent
Incongruent
-Posture
E
The two possible postures of the participant
MONITOR
YOU
anticlockwise
clockwise

Figure 2

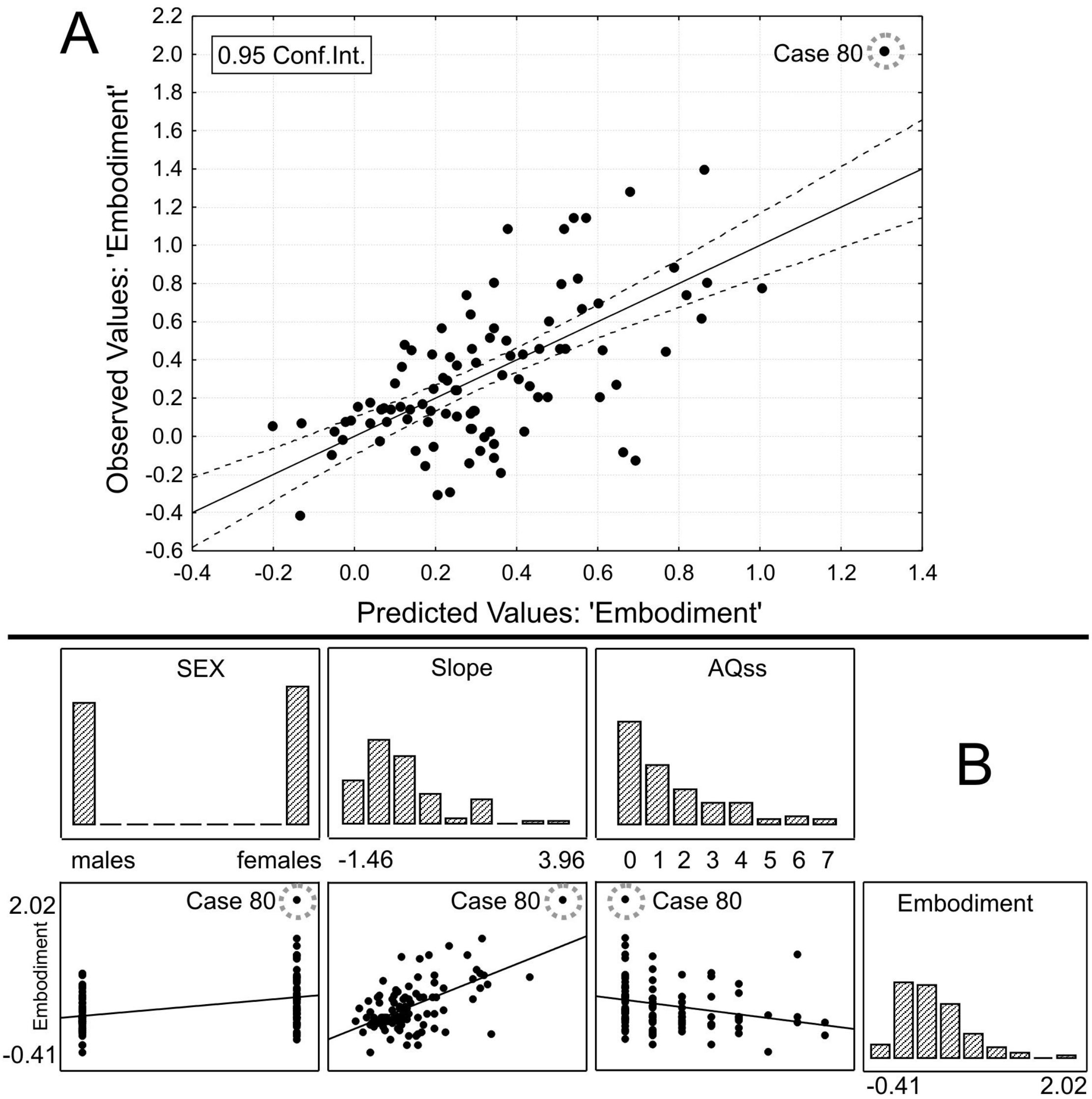
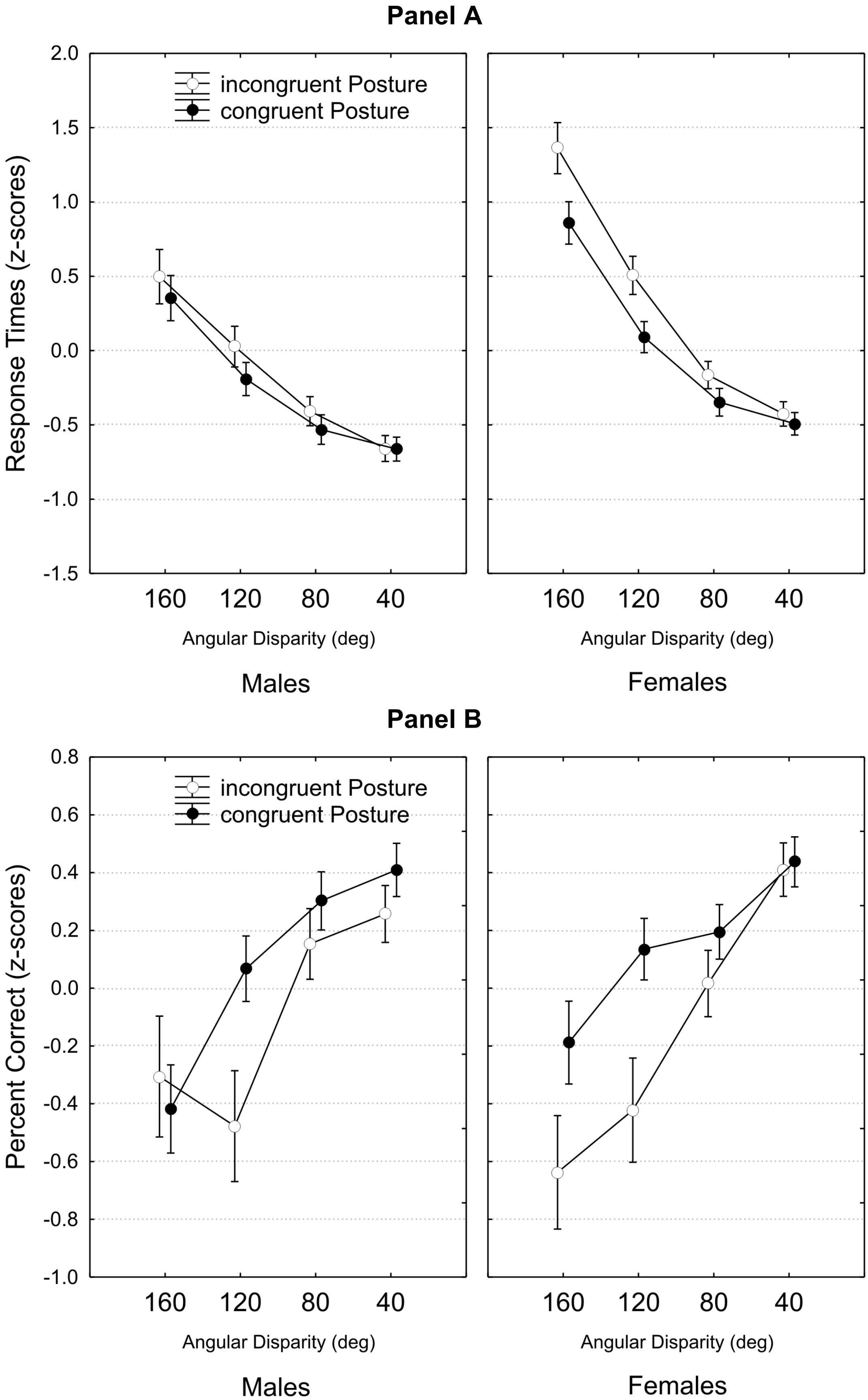

A
0.95 Conf.Int.
Case 80
Observed Values: 'Embodiment'
Predicted Values: 'Embodiment'
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
B
SEX
Slope
AQss
males
females
-1.46
3.96
0 1 2 3 4 5 6 7
2.02
-0.41
Embodiment
Case 80
Case 80
Case 80
Embodiment
-0.41
2.02

Figure 3


Panel A
incongruent Posture
congruent Posture
Response Times (z-scores)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
160
120
80
40
Angular Disparity (deg)
Males
Females
Panel B
Percent Correct (z-scores)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0