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ORIGINAL ARTICLE

Does belief in free will influence biological motion perception?

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Abstract

Previous research suggests that belief in free will correlates with intentionality attribution. However, whether belief in free will is also related to more basic social processes is unknown. Based on evidence that biological motion contains intentionality cues that observers spontaneously extract, we investigate whether people who believe more in free will, or in related constructs, such as dualism and determinism, would be better at picking up such cues and therefore at detecting biological agents hidden in noise, or would be more inclined to detect intentionality cues and therefore to detect biological agents even when there are none. Signal detection theory was used to measure participants' ability to detect biological motion from scrambled background noise (d') and their response bias (c) in doing so. In two experiments, we found that belief in determinism and belief in dualism, but not belief in free will, were associated with biological motion perception. However, no causal effect was found when experimentally manipulating free will-related beliefs. In sum, our results show that biological motion perception, a low-level social process, is related to high-level beliefs about dualism and determinism.

Introduction

Abraham Lincoln once said: "To believe in the things you can see and touch is no belief at all, but to believe in the unseen is a triumph and a blessing." From a daily life perspective, beliefs are mental constructs of which one cannot easily prove the existence but that still have a great influence on our personal life. Among those beliefs, religious or philosophical beliefs are often considered high-level beliefs (Hill & Whistler, 2013, p. 91–93). Common examples of such high-level beliefs are just-world beliefs (Lerner & Simmons, 1966), mind–body dualism beliefs (Nadelhoffer et al., 2014), and paranormal beliefs (Tobacyk, 2004). However, another extremely important class of high-level beliefs is free will beliefs (Genschow et al., 2017).

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The existence of free will has been a topic of debate throughout human history, both in academia and in daily life. In the beginning, this debate was mostly restricted to philosophy (Kane, 2011; Van Inwagen, 1983). More recently, however, cognitive psychologists have also started to contribute by studying the unconscious determinants of volitional behavior. A key finding from this work is that preparatory brain activity occurs already a couple of hundred milliseconds or even seconds before participants are aware of their motor intention (Libet, 1985; Libet et al., 1993; Soon et al., 2008). These findings have often been used as an argument against free will and caused the idea that free will does not exist to spread throughout society (Brass et al., 2019). This is important because research suggests that free will beliefs can influence social behavior, thoughts, and feelings, as well as more fundamental processes of social cognition. For example, studies have shown that reducing individuals' belief in free will triggers antisocial behavior, such as cheating (Vohs & Schooler, 2008; but see also Nadelhoffer et al., 2019 for failed replications), aggressiveness (Baumeister et al., 2009), and reduced feelings of gratitude (MacKenzie et al., 2014).

According to a prominent view, these effects exist because free will forms the basis for moral responsibility (Nahmias et al., 2007; Sarkissian et al., 2010). That is, if free will does not exist, then we are not in control and cannot be held accountable for our actions. As a result,

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weakening belief in free will reduces the motivation to control our urges and leads to more antisocial behavior (Lynn et al., 2013; Rigoni et al., 2012). Supporting this argument, research has found that weakening belief in free will indeed reduce intentional control (Lynn et al., 2013; Rigoni et al., 2011). While some of this research have been difficult to replicate (Caspar et al., 2017; Crone & Levy, 2019), and a recent meta-analysis questions downstream effects of free will belief manipulations (Genschow et al., 2021), correlational research has provided robust evidence for a relationship between free will beliefs and social behavior (Feldman et al., 2016; Genschow et al., 2019; Mercier et al., 2020; Seto et al., 2020; Stillman et al., 2010).

But how does belief in free will affect social perception? If people's feeling of control is weakened, do they then perceive other people as less intentional? To address this question, Genschow et al., (2017) investigated whether belief in free will can reduce the fundamental attribution error: the tendency to attribute other people's behavior more to internal intentions than to situational influences (Gilbert & Malone, 1995). The results revealed that belief in free will was indeed negatively correlated with this bias and that experimentally reducing free will beliefs likewise reduced internal attributions. Similarly, in a study where participants had to evaluate the intentionality of soccer players committing ambiguous handballs, Genschow et al. (2019) found that participants' belief in free will correlated positively with perceived intentionality. In addition, a similar correlation was also found when participants were asked to judge the intentionality of moving abstract geometrical shapes (Genschow et al., 2019; Heider & Simmel, 1944). In sum, these results suggest that belief in free will not only causes us to experience intentional control over our own actions but also to perceive intention in others.

A key question, however, is whether belief in free will is also related to more fundamental social processes. An important such process is biological motion processing. Throughout evolution, human beings have developed an ability to recognize and interpret the movements of biological agents (Rutherford & Kuhlmeier, 2013, p. 11–12). This, in turn, is essential for inferring the goals and intentions of other people and animals (Troje et al., 2013). Biological motion is often studied using point-light displays (Johansson, 1973, 1976), in which the main joints of the human body are represented as a constellation of dots. Research suggests that these moving point-light animations carry a wealth of socially meaningful information that observers spontaneously extract, including age (Montepare & Zebrowitz-McArthur, 1988), gender (Cutting & Kozlowski, 1977), mood (Chouchourelou et al., 2006; Dittrich et al., 1996), and personality traits (Heberlein et al., 2004; Troje, 2008). Most importantly, point-light animations also provide intentionality cues (Hohmann et al., 2011; Sebanz & Shiffrar, 2009). For example, research has shown that observers can derive from point-light displays whether or not an actor lifting a box is trying to deceive others about the true weight of the box (Runeson & Frykholm, 1983).

Based on evidence that people who believe in free will are more sensitive to intentionality cues (Genschow et al., 2017, 2019) and on evidence that intentionality cues contribute to biological motion perception (Troje et al., 2013), we hypothesized that belief in free will would correlate with biological motion perception. More specifically, consistent with Bayesian models of perception (de Lange et al., 2018; Press et al., 2020), we hypothesized that free will believers have a stronger prior for perceiving stimuli as intentional and therefore would be more likely to interpret ambiguous motion stimuli as biological motion stimuli (Andersen, 2019; Clark, 2015). To test this hypothesis, we showed noisy motion patterns that either did or did not contain a point-light walker and correlated performance in this task with free will beliefs. According to the Bayesian model framework, two outcomes are possible. First, because they are sensitive to intentional behavior, individuals who believe in free will (or in related beliefs such as determinism or dualism; Wisniewski et al., 2019) might be better at picking up intentionality cues and therefore better at detecting biological agents in noise (high sensitivity). Alternatively, however, free will believers might also see intentionality cues in random noise, leading them to perceive biological agents even when there are none (high response bias). In the current study, we tested these two possible outcomes by using Signal Detection Theory (SDT) to measure both participants' sensitivity and response bias for perceiving biological motion. In Experiment 1, we first investigated whether belief in free will is correlated to biological motion perception. In Experiment 2, we then went one step further and experimentally manipulated belief in free will.

Experiment 1

Materials and methods

Ethics statement

Both experiments were conducted on Prolific (Palan & Schitter, 2018). Before starting the experiment, participants gave informed consent. All procedures were approved by the local ethics committee of the Faculty of Psychology and Educational Sciences at Ghent University.

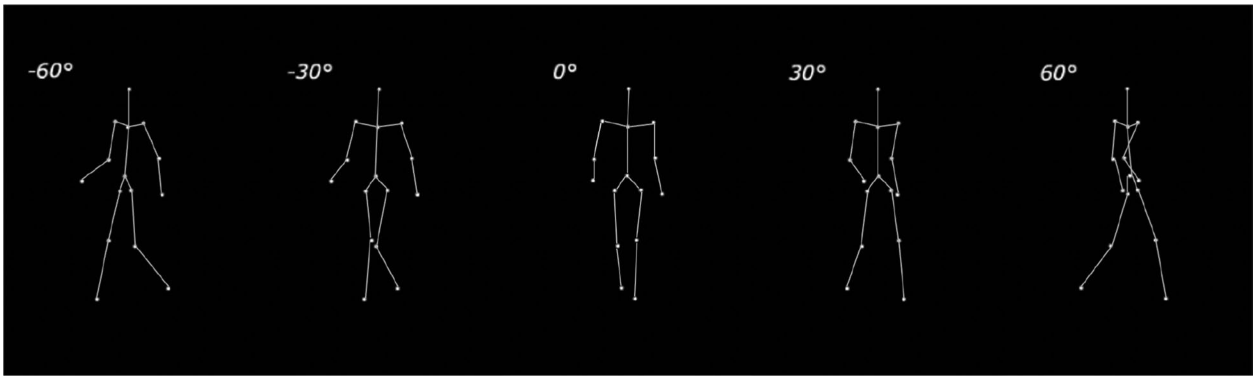

Fig. 1 Example of six orientations of walkers in this study. Note that the lines connecting the dots are included only for illustrative purposes and were not shown in the actual experiment

Participants

We originally preregistered the study at https://aspredicted.org/ff5gr.pdf. In this preregistration, we planned to use the average score of the Free Will Index (see below). However, before starting data collection, we discovered that the different subscales of this questionnaire are often not or inversely correlated. We therefore decided to update our preregistered analysis plan to use the separate subscales (https://aspredicted.org/uq5ut.pdf). All participants included in the current study were tested after updating the preregistration. Participants performed two tasks testing two different hypotheses. Only one task will be reported here, but the sample size was based on a power analysis for the other task. That is, our goal was to obtain 80% power to detect an effect of the same size we had found in a previous study using that task ($r = 0.13$). The power analysis revealed that this required $N = 364$. However, as preregistered, we tested 420 participants to compensate for potential drop-out. After removing participants who entered the experiment but did not complete it (e.g., no survey data), 405 valid participants were retained (198 women, 207 men). Participants were fluent in English and ranged in age from 18 to 40 ($M = 27.17$ years, SD = 5.87 years). Every participant recruited from the platform received at least £5/h for successful participation.

Stimuli, task, and procedure

This study consisted of two experimental tasks, created using the BMLkit (see http://www.biomotionlab.ca/Experiments/) and a series of questionnaires. First, participants were directed to an interface providing general information about the study. On the interface, participants saw an introductory text explaining the two following tasks. The first task (~ 5 min) was included in the context of another project and will not be discussed here. In the second task, participants had to decide on each trial whether they saw a point-light walker or not. Stimuli consisted of either a regular or scrambled point-light walker, combined with three types of scrambled background noise (43 dots vs. 61 dots vs. 88 dots), leading to 6 types of stimuli in total (see *Supplementary material*) (Thompson et al., 2008). Each walker consisted of 15 dots, corresponding to the main joints of the human body, and was rendered in white on a black background, using an orthographic camera with a horizontal optical axis. The orientation of the walker with respect to that axis was counterbalanced (− 60°, − 30°, 0°, 30°, or 60°) across trials in random order (see Fig. 1) and the initial phase of the walking movement in each trial was randomized between 360° and 0° in increments of 30°. The scrambled walker was generated by scrambling the walker's dots along the *x* and *y* axes within the same area occupied by the intact walker. The scrambled mask was generated by randomly sampling dots from the walker and then placing them at random positions within the whole display area while retaining their local motion. Each stimulus was presented for 2 s, followed by two response buttons prompting participants to indicate whether they had seen a walker or not. The response deadline was 4 s and the inter-trial interval 0 s. In total, each participant was presented with 180 trials.

After completing this task, participants completed a series of questionnaires on LimeSurvey 3.15. Belief in free will was measured using the Free Will Inventory (FWI) (Nadelhoffer et al., 2014). Compared to the other existing scales, like the Free Will and Scientific Determinism scale (FAD-4) (Paulhus & Margesson, 1994) and the Free Will and Determinism Scale (FAD-Plus) (Paulhus & Carey, 2011), the FWI is known to have better validity and to provide more information on how people think about the complex relationships among free will, responsibility, dualism, choice, determinism, and related concepts (Nadelhoffer et al., 2014). The FWI measures three beliefs related to free will, namely, belief in free will (FW), belief in determinism (DE), and belief in dualism (DU), and consists of two parts. The first part contains 15 items and measures the strength of people's beliefs. The second part consists of 14 items and explores the relationships between the three measured beliefs. In the current experiment, participants only completed the first part of the FWI, using a 7-point Likert scale ranging from "Strongly disagree" to "Strongly agree." After completing the FWI, participants also completed the abbreviated internal–external locus of control scale (Valecha & Ostrom, 1974) and a series of questions asking participants to estimate the price of a variety of products. The locus of control scale was included because the concept of locus of control is closely related to that of belief in free will (Waldman et al., 1983). Hence, we included this scale to rule out that our results were explained by locus of control rather than by free will beliefs. The pricing questions were included to pilot stimuli for a third project and will not be reported here.

Data analysis

We excluded participants based on two criteria. First, we excluded participants who provided the same response on more than 90% of the trials. Second, we also excluded participants whose accuracy across the three different conditions was below chance level (i.e., 50%). In addition to these two preregistered exclusion criteria, we also applied two non-preregistered exclusion criteria. First, we excluded participants with excessive missing data. That is, because this was an online experiment, sometimes not all trials were saved on the server. While there were no ($N = 397$) or only limited ($N = 7, < 20\%$) missing data for most participants, a large number of trials ($\geq 95\%$) were missing for 1 participant. This one participant was excluded. Second, upon exploring the data, we noticed that there were a number of participants with an extreme response bias (see Supplementary Fig. S2). Given that correlations are highly susceptible to such outliers, we therefore decided post hoc to exclude response bias outliers using the Inter-Quartile Range (IQR) method ($N = 10$). After the above exclusions, 380 participants (183 women, 197 men, age ranges from 18 to 40, $M = 27.19$ years, $SD = 5.83$ years) were retained.

To test our hypothesis, as preregistered, we conducted two repeated measures ANCOVAs: one with sensitivity as the dependent variable and another one with response bias as the dependent variable. In both ANCOVAs, we included the three noise levels as a within-subjects factor and free will beliefs as a covariate. This analysis was done separately for each of the three FWI subscales. We expected a relationship between free will-related beliefs, especially the FW and DE subscales, and both dependent variables, possibly interacting with the level of noise. Furthermore, we expected that these effects would still be present when locus of control was added as a covariate to the model to control for its influence. All ANCOVAs were performed using the "afex" package in R (Singmann et al., 2015). Finally, we also calculated Bayes Factors (BFs) for all the key analyses using JASP (https://jasp-stats.org/), in which we used BF_{10} to measure the strength of evidence for supporting alternative hypothesis compared to null hypothesis. The BFs are included to provide additional guidance about the strength of the evidence. If $BF_{10} < 0.33$, this can be interpreted as substantial evidence in favor of the null hypothesis. If $BF_{10} > 3$, this can be interpreted as substantial evidence in favor of the alternative hypothesis (Keysers et al., 2020).

Sensitivity and response bias were calculated using "psycho" package in R (Makowski, 2018) by first sorting trials into four categories (hit, miss, correct rejection, and false alarm) and then computing indices of sensitivity and response bias as proportions of these trials. Sensitivity (d') reflects the ability to detect biological motion from background noise and is calculated as the Z-value of the hit rate minus that of the false alarm rate ($d' = Z(P_H) - Z(P_{FA})$). Although we had initially planned to use β as a measure of response bias, we learned afterward that this measure is not independent of d' (Stanislaw & Todorov, 1999). Therefore, we decided to replace it with the now more commonly used c measure. This measure reflects the tendency of responding "yes" or "no" to the stimuli and is calculated as the additive inverse of the average of the z scores corresponding to the hit rate and the false alarm rate ($c = -(Z(P_H) + Z(P_{FA}))/2$). The more participants tend to respond "yes" (i.e., a liberal response bias), the smaller the c value is. In contrast, the more participants tend to respond "no" (i.e., a conservative response bias), the bigger the c value is. In our study, a more liberal bias reflects a higher tendency to report seeing the walker in the background noise.

Results

Descriptive statistics

In the current sample, the mean scores of Free Will Subscale (FW), the Determinism Subscale (DE), and the Dualism Subscale (DU) of the Free Will Inventory (FWI) were 4.61 ($SD = 5.65$, $\alpha = 0.78$), 3.65 ($SD = 5.75$, $\alpha = 0.83$) and 4.46 ($SD = 6.89$, $\alpha = 0.75$), respectively. The mean score of the abbreviated internal–external locus of control scale was 2.55 ($SD = 5.87$, $\alpha = 0.70$).

Preregistered analyses

The sensitivity (d') ANCOVAs indicated a main effect of background noise in all three models (i.e., with FW, DU, or DE as covariate), all $F(2, 756) \geq 17.40$, all $p < 0.001$, all partial $\eta_2 \geq 0.044$, $BF_{10} > 1000$, showing that sensitivity decreased as background noise increased. In addition, there were significant negative relationships between FW

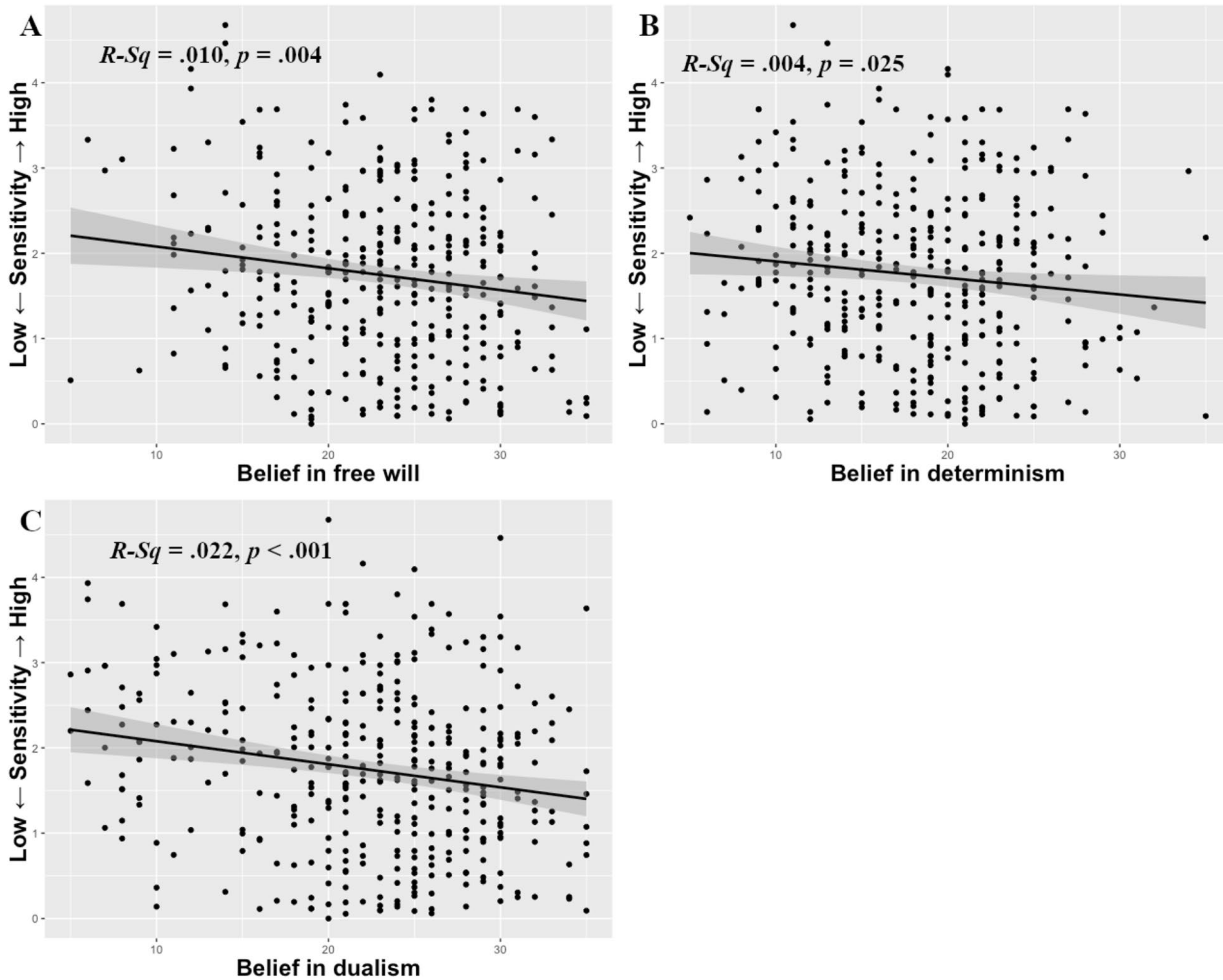

Fig. 2 Scatter plot of the relationships between the three FWI subscales and sensitivity in Experiment 1. **A** The scatter plot between Free Will belief and sensitivity. **B** The scatter plot between Determinism belief and sensitivity. **C** The scatter plot between Dualism belief and sensitivity. The R-squared and *p* value are taken from the ANCOVA model including the respective scale

and sensitivity $F(1, 378) = 8.38$, $p = 0.004$, partial $\eta_2 = 0.022$, $BF_{10} = 9.44$, between DE and sensitivity $F(1, 378) = 5.06$, $p = 0.025$, partial $\eta_2 = 0.013$, $BF_{10} = 2.31$, and between DU and sensitivity, $F(1, 378) = 15.20$, $p < 0.001$, partial $\eta_2 = 0.039$, $BF_{10} = 186.02$ (see Fig. 2). These relationships indicated that participants who believed more in free will, determinism, or dualism were worse at detecting biological motion in the task. Importantly, all three relationships remained significant even when locus of control was controlled by adding this variable as an additional covariate (all $p \leq 0.025$).

The response bias (*c*) ANCOVAs likewise indicated a main effect of background noise in all three models, all $F(2, 756) \geq 20.03$, all $p < 0.001$, all partial $\eta_2 \geq 0.050$, $BF_{10} > 1000$, indicating that participants became more conservative as noise increased. In addition, there was a significant negative relationship between DE and the response bias, $F(1, 378) = 5.18$, $p = 0.023$ partial $\eta_2 = 0.014$, $BF_{10} = 1.72$ (see Fig. 3), indicating that participants who believed more in determinism responded more liberally in the task. Importantly, this relationship remained significant even when locus of control was controlled ($p = 0.022$). The relationships between FW and the response bias, $F(1, 378) = 1.78$, $p = 0.183$, partial $\eta_2 = 0.005$, $BF_{10} = 0.42$, and between DU and the response bias, $F(1, 378) = 3.59$, $p = 0.059$, partial $\eta_2 = 0.009$, $BF_{10} = 0.88$, were not significant.

Exploratory analyses

Our preregistered analysis indicated that FW, DU, and DE were all similarly related to d', even though belief in determinism is often seen as the opposite of belief in free will (Kane, 2004). As the FWI does not contain reverse-coded items, part of these relationships could be the result of shared methods variance, such as an acquiescence bias (Baron-Epel et al., 2010). In the next step, we therefore

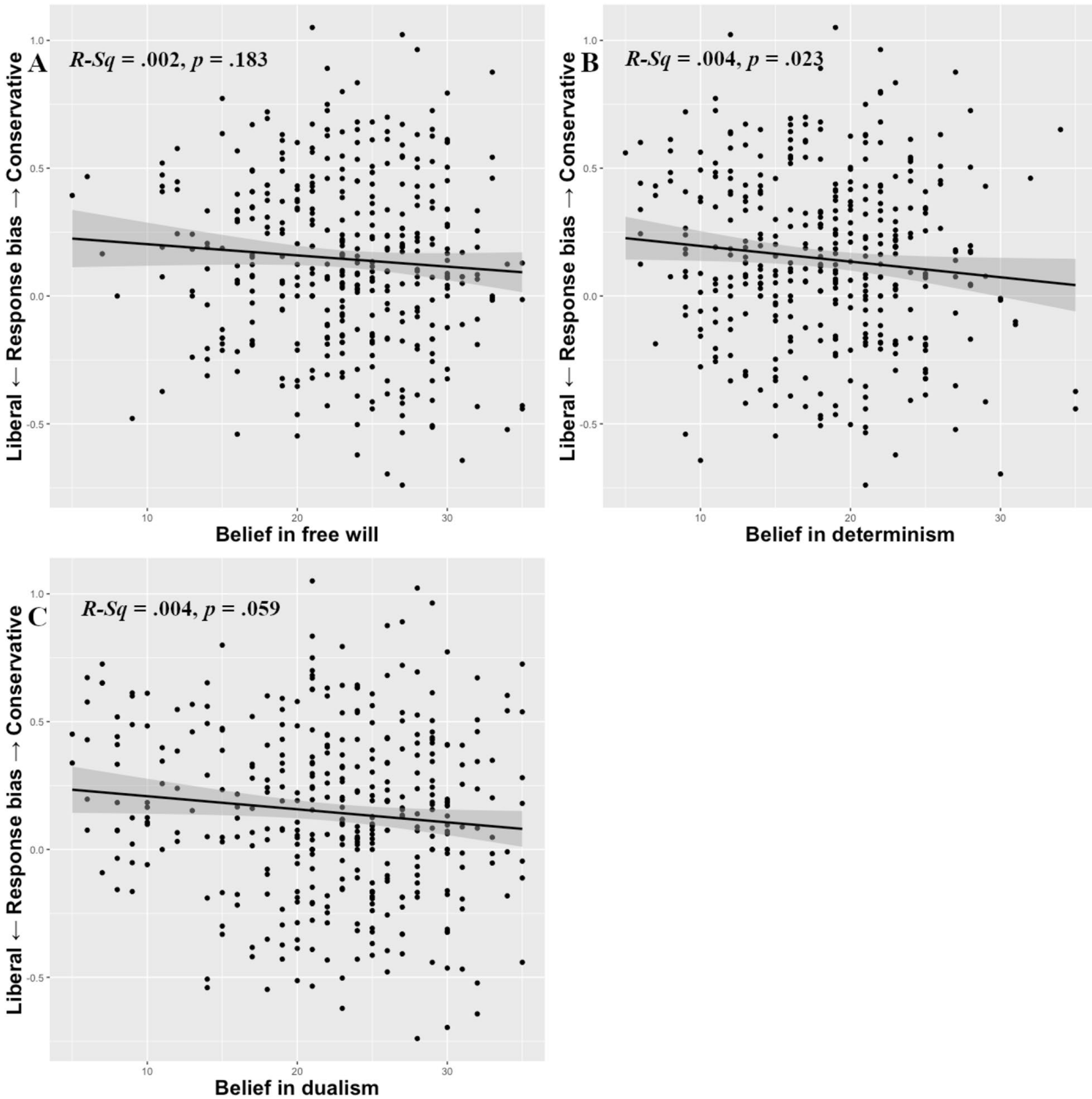

Fig. 3 Scatter plot of the relationships between the three FWI subscales and response bias in Experiment 1. **A** The scatter plot between Free Will belief and response bias. **B** The scatter plot between Determinism belief and response bias. **C** The scatter plot between Dualism belief and response bias. The R-squared and *p* value are taken from the ANCOVA model including the respective scale

conducted an exploratory analysis investigating the unique variance explained by each FWI subscale. To this end, we repeated the above analyses with all three subscales (i.e., FW, DE, and DU) included simultaneously as covariates. The sensitivity analysis indicated a significant negative relationship between FW and sensitivity, $F(1, 376) = 3.91$, $p = 0.049$, partial $\eta_2 = 0.010$, $BF_{10} = 1.37$, and between DU and sensitivity, $F(1, 376) = 9.49$, $p = 0.002$, partial $\eta_2 = 0.025$, $BF_{10} = 14.83$, but no significant relationship between DE and sensitivity, $F(1, 376) = 0.061$, $p = 0.435$, partial $\eta_2 = 0.002$, $BF_{10} = 0.32$. The bias analysis indicated no significant negative relationship between FW and the response bias, $F(1, 376) = 0.39$, $p = 0.533$, partial $\eta_2 = 0.001$, $BF_{10} = 0.32$, between DE and the response bias, $F(1, 376) = 2.69$, $p = 0.102$, partial $\eta_2 = 0.007$, $BF_{10} = 0.94$, or between DU and the response bias, $F(1, 376) = 1.42$, $p = 0.234$, partial $\eta_2 = 0.004$, $BF_{10} = 0.53$. Together, this indicates that only dualism and free will beliefs were reliably related to sensitivity and that none of the three beliefs had a unique relation with the response bias.

Interim discussion

Previous research has shown that believing in free will is associated with increased intentional control and with increased attribution of intention to the behavior of others (Lynn et al., 2013; Rigoni et al., 2011). Here, we investigated whether belief in free will is also related to more fundamental social processes underlying intentionality attribution, such as biological motion perception (Hohmann et al., 2011; Runeson & Frykholm, 1983; Sebanz & Shiffrar, 2009). Specifically, we hypothesized that belief in free will and to a lesser extent belief in determinism and belief in dualism would be associated with biological motion detection.

Separate analyses of belief in free will, belief in determinism, and belief in dualism showed that all three beliefs correlated negatively with participants' sensitivity to biological motion. However, only belief in determinism correlated with participants' response bias. Specifically, participants with higher beliefs in determinism were more inclined to report that there was biological motion. A follow-up analysis including all scales together in the same model showed that only belief in dualism and belief in free will explained unique variance in perceptual sensitivity and that none of the three scales was correlated with response bias after accounting for the other scales. Overall, this suggests that the three scales might have shared variance and that after excluding this shared variance, only belief in dualism and belief in free will are related to participants' sensitivity in seeing biological motion. More specifically, our results indicate that people who believe more in free will or dualism are less sensitive to biological motion.

Interestingly, this pattern of results contradicts our original hypothesis of a positive correlation between especially belief in free will and biological motion detection. However, given that it was not expected, replication is warranted. Moreover, given that this was a correlational study, our results do not speak to the causality of the effects. Therefore, to confirm our findings and to establish causality, we ran a second study, in which we experimentally manipulated belief in free will by means of anti-free will messages (Genschow et al., 2017) to see whether this influences biological motion detection. In line with Experiment 1, we predicted that priming participants with messages that free will does not exist would result in lower sensitivity to biological motion compared with priming participants with messages unrelated to free will.

Experiment 2

Materials and methods

Participants

We first preregistered the study at https://aspredicted.org/7bs3v.pdf. However, due to the extremely high exclusion rate after performing the preregistered manipulation check on the initial 20 participants, we updated the preregistration with an adjusted manipulation check (see updated preregistration: https://aspredicted.org/p88ff.pdf). As before, the participants initially tested with the original preregistration were not included in the final sample. We planned to collect data from 350 participants. This sample size was based on a power analysis using the data from Experiment 1. In Experiment 1, effect sizes were relatively small, and transforming the correlations of belief in free will and belief in dualism with d' to Cohen's d indicated respective effect sizes of $d=0.39$ and $d=0.26$.[1] Using the mean of these two values in a power analysis ($d=0.33$) indicated that 300 participants were needed to obtain 80% power to detect an effect size for the manipulation similar in size to the correlational effects obtained in Experiment 1. However, we decided to collect 350 participants to compensate for potential dropout. In addition, we also preregistered that we would add 50 more participants if the sample after exclusions dropped below 300 participants until our sampling goal of $N \geq 300$ was achieved. Eventually, 395 participants were included in this study (151 women, 240 men, 4 unknown). Participants were fluent in English and ranged in age from 18 to 40 ($M=25.96$ years, SD $=6.04$ years). Every participant recruited from the platform received at least £5/h for successful participation.

Stimuli, task, and procedure

This study consisted of four parts: a free will manipulation, the biological motion detection task, a secondary task, and a series of questionnaires. First, participants were directed to an interface containing information about the study and the informed consent form. On the interface, participants saw a basic introduction of the different tasks and clearly stated steps. Next, participants were randomly and equally assigned one of two groups. Half of the participants were assigned to the anti-free will group and the other half to the control group. All participants first read a text introducing Francis

[1] A correlation of $r=0.13$ was used for belief in free will in the power calculation but the actual correlation is $r=0.15$. The difference is due to the fact that the initial correlation did not take into account all exclusion criteria.

Crick and then a paragraph adopted from his book < <*The Astonishing Hypothesis: The Scientific Search for the Soul*> >(Crick, 1994) (see "Appendix A"). Participants in the anti-free will group read a paragraph arguing that free will is an illusion and can be explained by neural activity, whereas participants in the control group read a paragraph about the general nature of consciousness (Genschow et al., 2017, 2019). After the free will manipulation, participants were asked to summarize the text in 2–3 sentences. In the next step, participants did the same biological motion task as in Experiment 1. After completing the biological motion task, participants did a second task, which was included for the purpose of another project and will not be discussed here. Finally, participants completed the FWI, a manipulation check, and three questions regarding *COVID-19* that were included for exploratory purposes and will not be discussed here. The manipulation check was a multiple-choice question with 5 response alternatives asking about the main theme of the text they had read at the start of the experiment.

Data analysis

We excluded participants based on three criteria. First, we excluded participants who provided the same response on more than 90% of the trials. Second, we excluded participants whose accuracy across the three different conditions was under 50%. Finally, we excluded participants who failed the free will manipulation attention check. That is, at the end of the experiment, participants were asked a question about the text they read at the beginning. We excluded participants who did not answer correctly to the question or who spent less than 45 s reading the text. In addition to these two preregistered exclusion criteria, we also added the same two non-preregistered exclusion criteria as in Experiment 1. That is, we excluded participants with excessive missing data ($N=0$, all participants had $\leq 21.11\%$ missing trials) and response bias outliers using the IQR method ($N=6$). After applying these exclusions, 294 participants (121 women, 170 men, 3 unknown gender, age ranges from 18 to 40, $M=26.18$ years, SD = 5.97 years) were retained,[2] 139 in the anti-free will group (63 women, 73 men, 3 unknown gender, $M=25.94$ years, SD = 6.11 years), and 155 in the control group (58 women, 97 men, $M=26.39$ years, SD = 5.84 years).

As preregistered, we first tested whether the manipulation was effective with an independent samples *t* test comparing the mean values of the three subscales in the anti-free will group and the control group. Next, we tested the influence of the manipulation on biological motion processing using two 2 (manipulation) × 3 (background noise) mixed measures ANOVAs: one with d' and one with c as the dependent variable. Note that in line with Experiment 1, we initially planned to use β as a measure of response bias but later decided to use c upon learning that β is not independent of d' (Stanislaw & Todorov, 1999). We expected an influence of manipulation type on both dependent variables, possibly interacting with the level of noise. Third, to replicate the correlational findings of Experiment 1, we also conducted the same ANOVAs as above, but now with the three scales (free will, dualism, and determinism) added together as covariates. We expected a relation between the scales (especially dualism) and the dependent variables, possibly interacting with level of noise or the manipulation. Finally, as preregistered, and in line with Experiment 1, we also repeated these ANCOVAs with each scale added separately to the model to assess these relationships without controlling for the other two subscales.

Results

Descriptive statistics

For the anti-free will group, the mean scores of the free will (FW), determinism (DE), and dualism (DU) subscales were 4.20 (SD = 6.19, $\alpha=0.85$), 3.45 (SD = 5.28, $\alpha=0.68$) and 3.85 (SD = 7.85, $\alpha=0.90$), respectively. For the control group, they were 4.45 (SD = 5.16, $\alpha=0.73$), 3.61 (SD = 5.27, $\alpha=0.72$) and 4.28 (SD = 6.45, $\alpha=0.83$), respectively.

Preregistered analyses

Manipulation check The manipulation check revealed that scores on the DU subscale were significantly lower in the anti-free will group than in the control group, $t(267.87)=-2.59$, $p=0.010$, *Cohen's* $d=-0.31$. There was no significant difference between the anti-free will and control group on the FW, $t(269.65)=-1.89$, $p=0.059$, *Cohen's* $d=-0.22$, or DE subscales, $t(292)=-1.30$, $p=0.194$, although the FW effect was close to significance.

Manipulation effect on sensitivity and bias The sensitivity (d') ANOVA indicated that sensitivity decreased as background noise increased, $F(2, 584)=157.47$, $p<0.001$, partial $\eta_2=0.350$, $BF_{10}>1000$. However, there was no effect of the manipulation, $F(1, 292)=0.62$, $p=0.432$, partial $\eta_2=0.002$, $BF_{10}=0.39$, nor an interaction between the manipulation and noise level, $F(2, 584)=0.80$, $p=0.451$, partial $\eta_2=0.003$, $BF_{10}=0.049$. Similarly, the bias ANOVA indicated that participants became more conservative as background noise increased, $F(2, 584)=167.05$, $p<0.001$,

[2] While we preregistered to add $N=50$ participants when the sample after exclusions dropped below $N=300$, we only decided on the last two exclusion criteria later (see Experiment 1 for rationale). Using only the preregistered criteria, the sample after exclusions was $N=300$. Hence, we did not test additional participants.

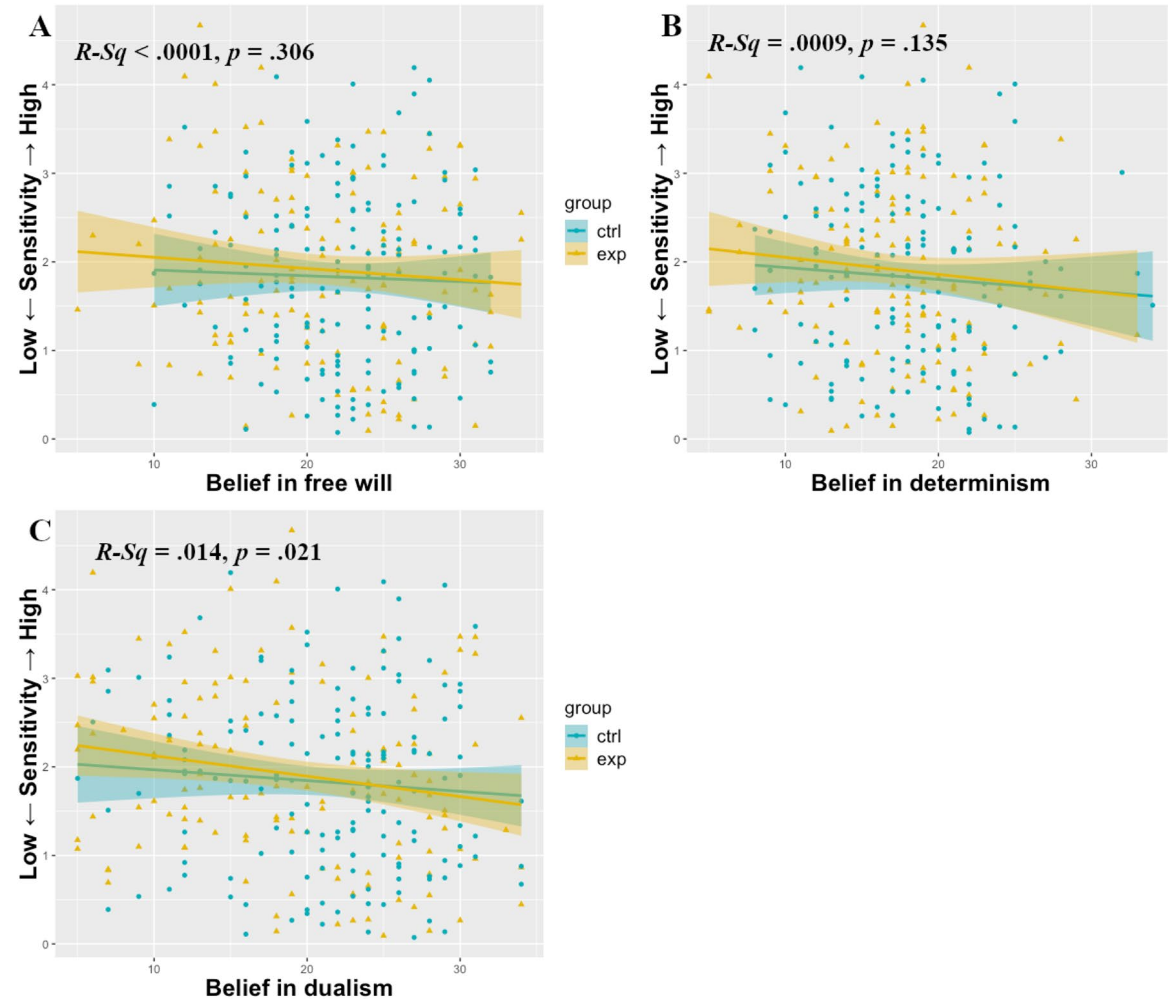

Fig. 4 Scatter plot of the relationships between the three FWI subscales and sensitivity in Experiment 2. **A** The scatter plot between Free Will belief and sensitivity. **B** The scatter plot between Determinism belief and sensitivity. **C** The scatter plot between Dualism belief and sensitivity. The R-squared and *p* value are taken from the ANCOVA model including the respective scale

partial $\eta_2 = 0.364$, $BF_{10} > 1000$. However, there was no effect of the manipulation, $F(1, 292) = 1.51$, $p = 0.220$, partial $\eta_2 = 0.005$, $BF_{10} = 0.35$, nor an interaction between the manipulation and noise level, $F(2, 584) = 0.17$, $p = 0.848$, partial $\eta_2 < 0.001$, $BF_{10} = 0.03$.

Relationship between free will beliefs and sensitivity and bias To analyze the relationship between belief in free will and biological motion perception, we first added each scale separately to the above ANOVA. The sensitivity analysis revealed a significant negative relationship between DU and sensitivity (d'), $F(1, 292) = 5.35$, $p = 0.021$, partial $\eta_2 = 0.018$, $BF_{10} = 2.09$, but not between the other two scales and sensitivity, $F(1, 292) \leq 2.24$, $p \geq 0.135$, partial $\eta_2 \leq 0.008$, $BF_{10} \leq 0.68$ (see Fig. 4). The response bias (c) analysis revealed a significant negative relationship between DE and bias $F(1, 292) = 4.39$, $p = 0.037$, partial $\eta_2 = 0.015$, $BF_{10} = 1.49$, but not the other two scales and response bias, $F(1, 292) \leq 2.66$, $p \geq 0.104$, partial $\eta_2 \leq 0.009$, $BF_{10} \leq 0.81$ (see Fig. 5).

Adding the three subscales together as covariates to the sensitivity ANOVA revealed no significant relationship with either FW, $F(1, 289) = 0.03$, $p = 0.860$, partial $\eta_2 < 0.001$, $BF_{10} = 0.35$, DE, $F(1, 289) = 1.40$, $p = 0.238$, partial $\eta_2 = 0.005$, $BF_{10} = 0.73$, or DU, $F(1, 289) = 3.40$, $p = 0.066$, partial $\eta_2 = 0.012$, $BF_{10} = 1.29$, although the relationship with DU was close to significance. Adding the same three scales to the bias ANOVA revealed a significant negative relationship between DE and bias, $F(1, 289) = 3.97$, $p = 0.047$, partial $\eta_2 = 0.014$, $BF_{10} = 1.70$, but not between bias and the other two scales, $F(1, 289) \leq 1.88$, $p \geq 0.172$, partial $\eta_2 \leq 0.006$, $BF_{10} \leq 0.68$. Thus, after controlling for shared variance, we find no robust relationship with sensitivity, but a negative relationship between belief in determinism and response bias, such that participants who believed more in determinism used a more liberal response style in the task.

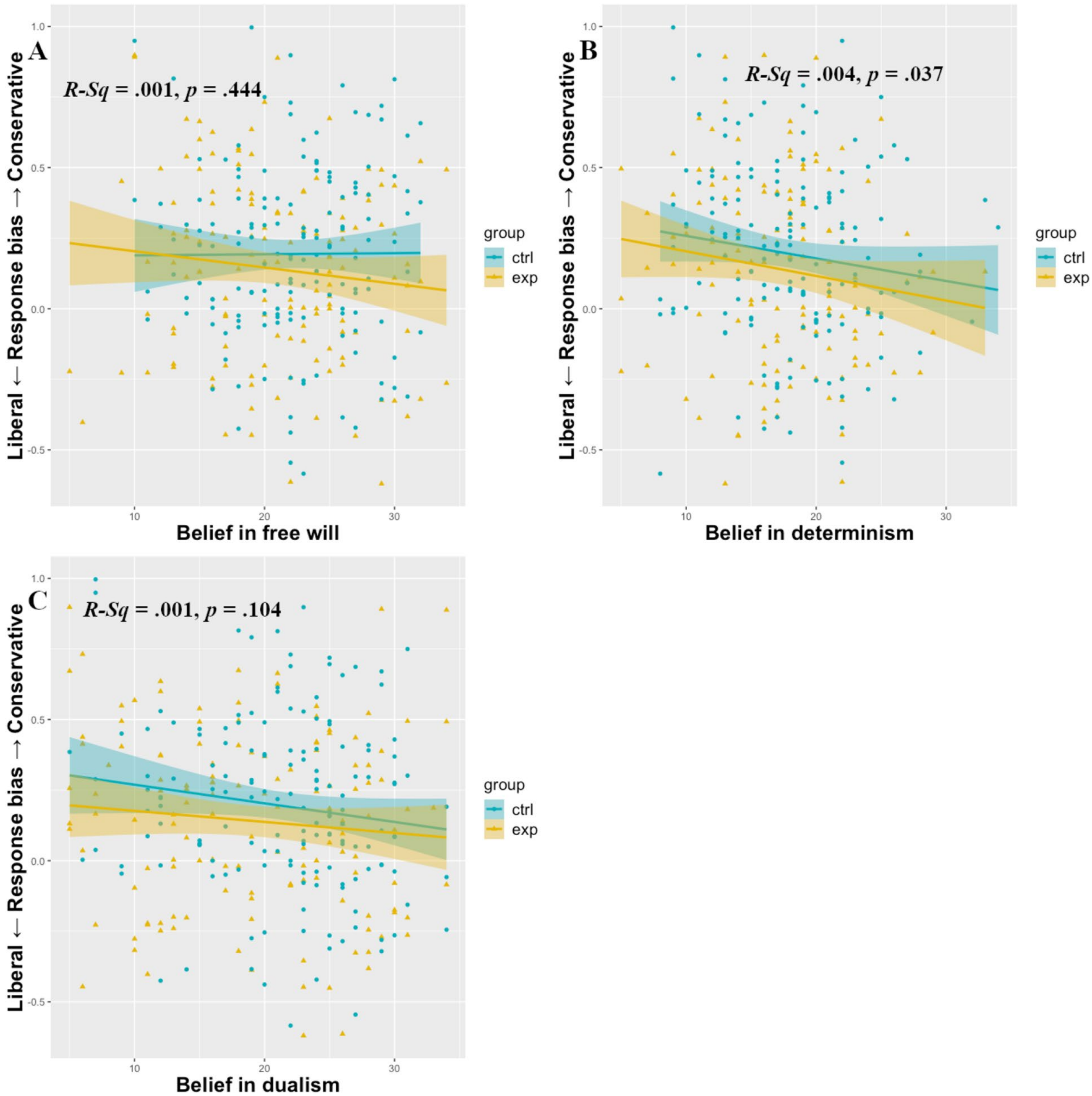

Fig. 5 Scatter plot of the relationships between the three FWI subscales and response bias. **A** The scatter plot between Free Will belief and response bias. **B** The scatter plot between Determinism belief and response bias. **C** The scatter plot between Dualism belief and response bias. The R-squared and *p* value are taken from the ANCOVA model including the respective scale

Interim discussion

Experiment 2 followed up on the findings of Experiment 1 by testing whether free will-related beliefs have a causal influence on biological motion detection. To this end, we manipulated belief in free will using an often-used scientific text (Crick, 1994). Although the manipulation check indicated that belief in dualism was significantly influenced by the scientific text, we found no effect of our manipulation on either sensitivity or response bias. We did, however, find similar relations between free will-related beliefs and biological motion perception as in Experiment 1. First, we replicated the relation between belief in dualism and sensitivity (although only when analyzing the scales separately). Second, we replicated the finding that participants who believed more strongly in determinism were more likely to report seeing biological motion.

In sum, Experiment 2 found no causal effect of free will-related beliefs on biological motion perception but did find

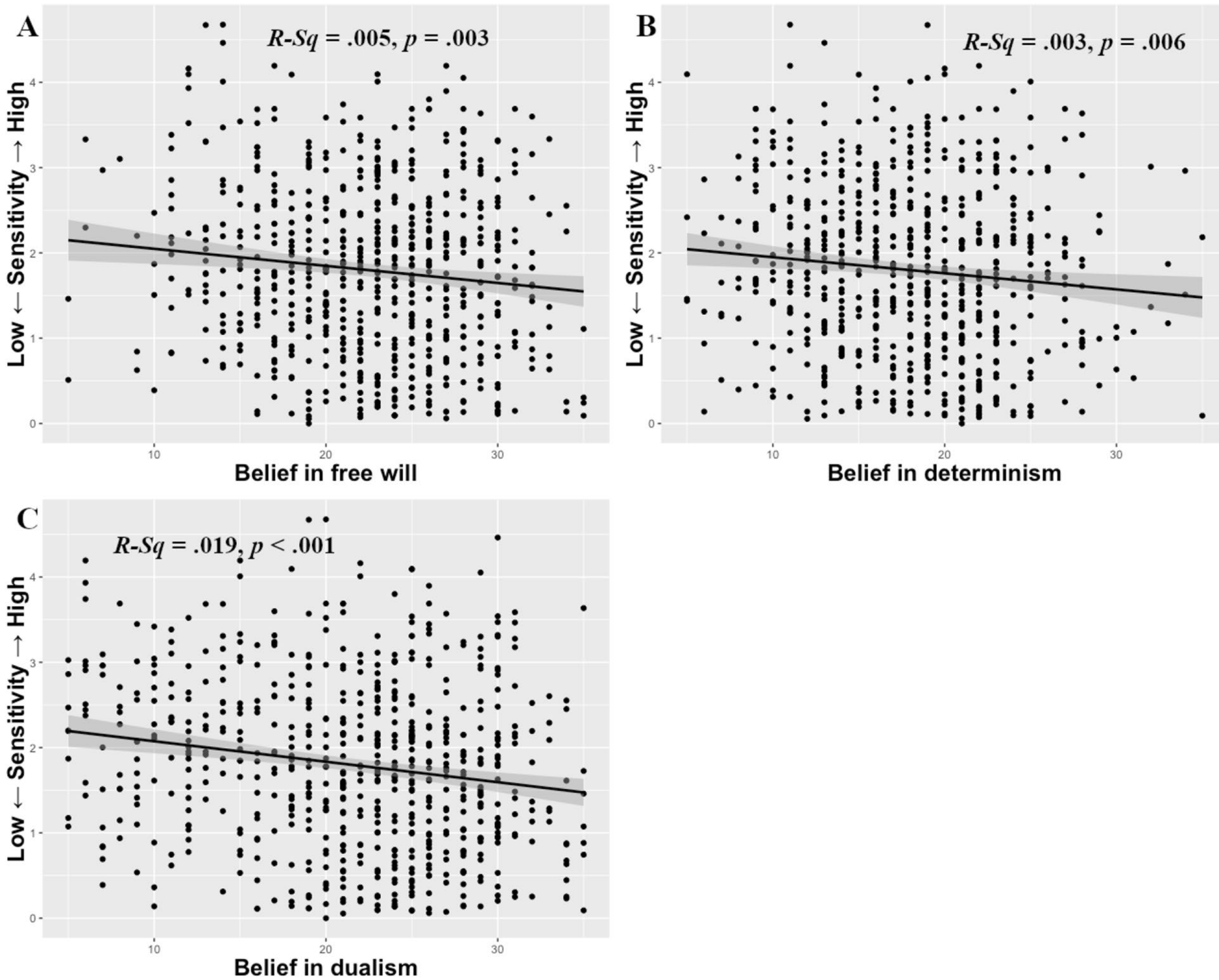

Fig. 6 Scatter plot of the relationships between the three subscales and sensitivity across Experiments 1 and 2. **A** The scatter plot between Free Will belief and sensitivity. **B** The scatter plot between Determinism belief and sensitivity. **C** The scatter plot between Dualism belief and sensitivity. The R-squared and *p* value are taken from the ANCOVA model including the respective scale

similar relationships between these beliefs and the perception of biological motion as Experiment 1. However, while similar, the correlations were not entirely consistent across experiments. That is, controlling for shared variance made the correlation between dualism beliefs and sensitivity disappear in Experiment 2 but not in Experiment 1 and made the correlation between determinism beliefs and response bias disappear in Experiment 1 but not Experiment 2. Importantly, the included Bayes Factors suggest that this may have been due to a lack of sensitivity, as we did not find strong evidence for the null hypothesis. To obtain a clearer picture of our data, we therefore decided to conduct an additional exploratory analysis in which we combined the data of our two experiments in a single large sample ($N = 674$).

Aggregate analysis

The sensitivity (d') ANCOVAs including the three scales, separately indicated a main effect of background noise in all three models, all $F(2, 1344) \geq 26.84$, all $p < 0.001$, all partial $\eta_2 \geq 0.038$, $BF_{10} > 1000$, with sensitivity decreasing as background noise increased. In addition, there were significant relationships between FW and sensitivity $F(1, 672) = 9.09$, $p = 0.003$, partial $\eta_2 = 0.013$, $BF_{10} = 12.25$, between DE and sensitivity $F(1, 672) = 7.66$, $p = 0.006$, partial $\eta_2 = 0.011$, $BF_{10} = 5.93$, and between DU and sensitivity, $F(1, 672) = 21.26$, $p < 0.001$, partial $\eta_2 = 0.031$, $BF_{10} > 1000$ (see Fig. 6). The response bias (c) ANCOVAs likewise indicated a main effect of background noise in all three models, all $F(2, 1344) \geq 32.42$, all $p < 0.001$, all partial $\eta_2 \geq 0.046$, $BF_{10} > 1000$, with participants becoming more conservative as noise increased. In addition, there were significant relationships between DE and bias, $F(1, 672) = 9.87$, $p = 0.002$,

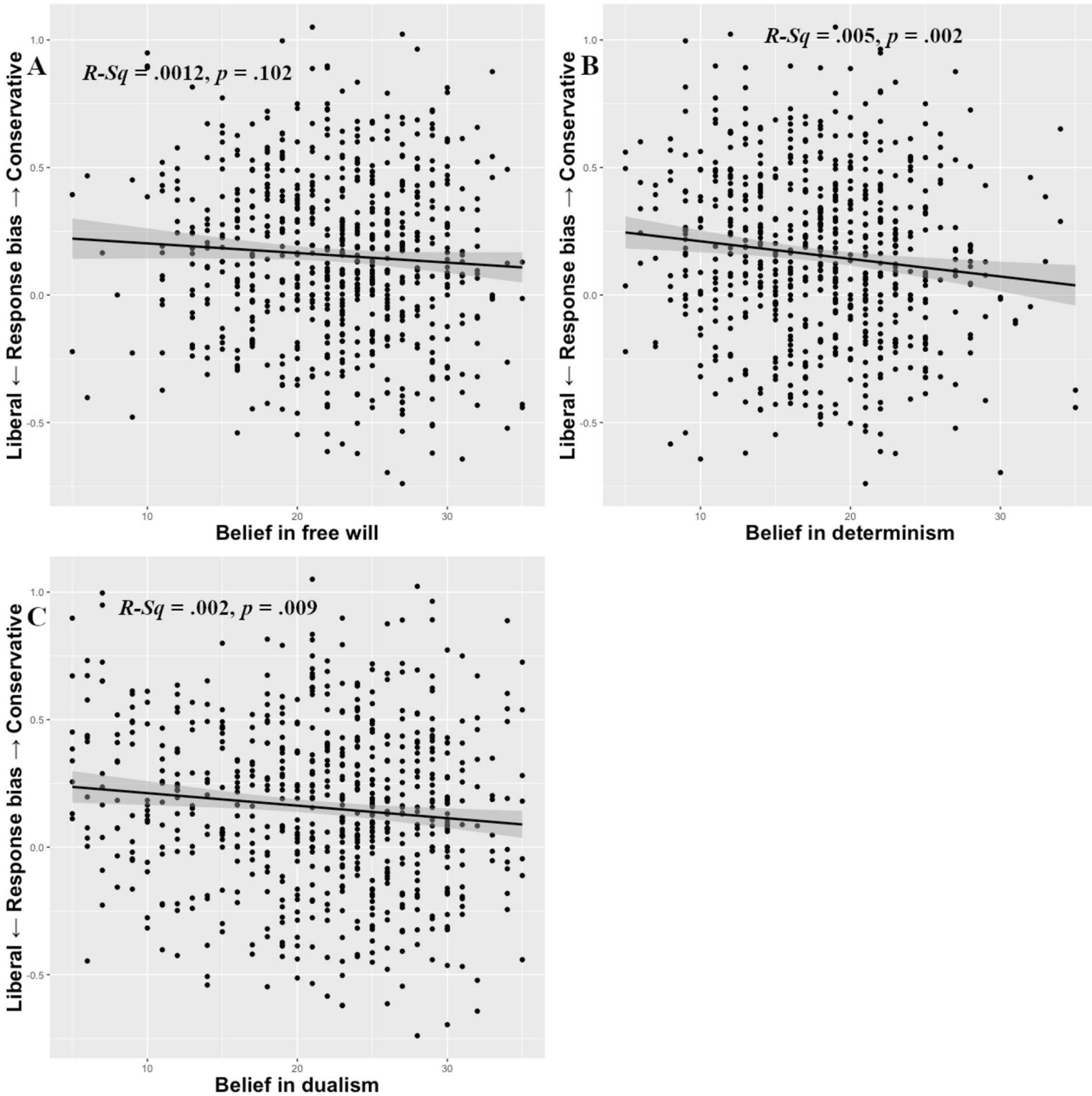

Fig. 7 Scatter plot of the relationships between the three FWI subscales and response bias across Experiments 1 and 2. **A** The scatter plot between Free Will belief and response bias. **B** The scatter plot between Determinism belief and response bias. **C** The scatter plot between Dualism belief and response bias. The R-squared and *p* value are taken from the ANCOVA model including the respective scale

partial $\eta_2 = 0.014$, $BF_{10} = 13.93$, between DU and bias, $F(1, 672) = 6.90$, $p = 0.009$, partial $\eta_2 = 0.010$, $BF_{10} = 3.23$, but not between FW and bias, $F(1, 672) = 2.68$, $p = 0.102$, partial $\eta_2 = 0.004$, $BF_{10} = 0.44$ (see Fig. 7).

Including all three subscales (FW, DE, and DU) together as covariates revealed a significant negative relationship between DU and sensitivity, $F(1, 670) = 12.40$, $p < 0.001$, partial $\eta_2 = 0.018$, $BF_{10} = 67.76$, but no relationship between FW and sensitivity, $F(1, 670) = 2.55$, $p = 0.111$, partial $\eta_2 = 0.004$, $BF_{10} = 0.60$, or between DE and sensitivity, $F(1, 670) = 2.62$, $p = 0.106$, partial $\eta_2 = 0.004$, $BF_{10} = 0.83$. The same analysis on the response bias (c) revealed a significant negative relationship between DE and response bias, $F(1, 670) = 6.42$, $p = 0.012$, partial $\eta_2 = 0.009$, $BF_{10} = 4.19$, but not between DU and response bias, $F(1, 670) = 2.99$, $p = 0.084$, partial $\eta_2 = 0.004$, $BF_{10} = 0.83$, or between FW and response bias, $F(1, 670) = 0.042$, $p = 0.519$, partial $\eta_2 < 0.001$, $BF_{10} = 0.24$.

To summarize, the combined analysis confirmed that belief in dualism was associated with lower sensitivity in

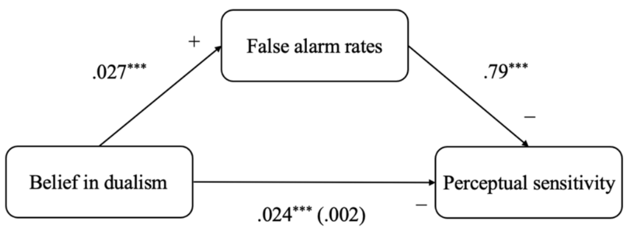

Fig. 8 Mediation analysis showing that the false alarm rate fully mediated the relationship between belief in dualism and perceptual sensitivity ($p < 0.001$)

detecting biological motion, belief in determinism with a more liberal response bias, and belief in free will with neither. While these findings go against our initial hypothesis, one potential explanation for the unexpected negative relationship between belief in dualism and sensitivity could be that people who believe in dualism tend to perceive social stimuli as intentional even when they are not and that this then leads to reduced sensitivity (Genschow et al., 2019). This is consistent with a previous study on the influence of paranormal beliefs on the perception of biological motion (Van Elk, 2013), showing that paranormal beliefs are inversely related to biological motion sensitivity and that this can be explained by a positive relationship with false alarm rates. To test whether a similar mechanism could also explain the relationship we observed between dualism beliefs and sensitivity, we ran a mediation analysis using the "mediation" package in R (Tingley et al., 2014). This indicated that, indeed, the relation between belief in dualism and perceptual sensitivity was fully mediated by the false alarm rate (see Fig. 8).

General discussion

Previous research has shown that people who believe more in free will assign more intention to other people's behavior (Genschow et al., 2017, 2019; Lynn et al., 2013; Rigoni et al., 2011), suggesting that belief in free will can bias perception by instating a prior expectation of intentional behavior (Andersen, 2019; Clark, 2015). Here, we investigated whether this same bias also affects more low-level social processes, such as the processing of biological motion. More specifically, based on evidence that biological motion contains important cues about agent intentionality (Hohmann et al., 2011; Sebanz & Shiffrar, 2009), we hypothesized that individuals who believe more in free will would be better or more prone to detect biological motion in scrambled noise.

Using a signal detection approach, we show that belief in free will as such is not correlated with perceptual sensitivity and response bias in detecting biological motion, which is contrary to our original hypothesis. However, we did find correlations with two beliefs related to belief in free will, namely, belief in dualism and belief in determinism. Specifically, we found that sensitivity was correlated with belief in dualism and bias with belief in determinism, such that people who believed more in dualism had lower sensitivity to biological motion and people who believed more in determinism were more prone to report seeing biological motion. Together, this provides preliminary support for the hypothesis that free will-related beliefs, like belief in determinism and belief in dualism, are correlated with low-level social processes, such as biological motion processing. Given that biological motion processing plays an important role in evaluating intentionality (Hohmann et al., 2011; Runeson & Frykholm, 1983; Sebanz & Shiffrar, 2009), these findings potentially suggest that the previously observed relationships between free will-related beliefs and intentionality attribution (Genschow et al., 2019) arise already at the visual level.

However, given that we did not find a relationship with belief in free will itself, but rather with belief in dualism and belief in determinism, an important question is what drove these correlations. With regard to dualism, previous research has shown that belief in dualism is strongly associated with paranormal beliefs (Willard & Norenzayan, 2013) and that believing in the paranormal is associated with an increased propensity to falsely report seeing biological motion and therefore with a reduced ability to correctly detect biological motion (Van Elk, 2013). Given that we found a similar negative relationship between dualism beliefs and biological motion detection sensitivity as those reported with paranormal beliefs (Van Elk, 2013), this suggests that dualism beliefs were associated with reduced perceptual sensitivity because people who believe in dualism are more prone to see illusory patterns in noise. Indeed, in line with this hypothesis, a mediation analysis indicated that the relationship between belief in dualism and perceptual sensitivity was fully mediated via false alarm rate. It is important to point out, however, that Willard et al. (2013) used a different scale than the Free Will Inventory (Nadelhoffer et al., 2014) to measure belief in dualism (i.e., the Dualism Scale; (Stanovich, 1989). It is therefore an open question whether dualism beliefs measured with the Free Will Inventory also correlate with paranormal beliefs, especially because the dualism scale of the Free Will Inventory only includes two items about the soul, whereas the other three items are about non-reductionism.

Interestingly, although inconsistent with our original prediction, an interpretation in terms of illusory pattern recognition can be explained with the same Bayesian framework (de Lange et al., 2018; Press et al., 2020). According to this framework, individuals who believe in dualism have a stronger prior for interpreting a set of stimuli as belonging together, causing them to more often perceive a walker (i.e., a pattern) in scrambled noise. Such an explanation is in line with previous research arguing that supernatural experiences are driven by strong, top-down expectations that dominate perception when bottom-up input is ambiguous (Andersen, 2019; Clark, 2015). The finding that increased belief in determinism was associated with a more liberal detection threshold, on the other hand, is more difficult to explain. One potential explanation might be that people who believe in determinism have a tendency to identify patterns in randomly moving dots. However, given that our mediation analysis indicated that this mechanism is likely to be at the basis of the dualism effects and given that belief in determinism and belief in dualism are typically seen as conflicting beliefs (Bear & Knobe, 2016; Nadelhoffer et al., 2014), this seems unlikely. Based on the observation that belief in determinism leads to reduced intentional control (Lynn et al., 2013; Rigoni et al., 2011), another explanation could therefore be that belief in determinism leads to a lower response threshold and hence a more liberal response style. However, one should be aware of the post hoc nature of this line of reasoning.

In addition to the fact that we did not expect the observed relationships, it is also important to keep in mind that our findings are correlational and that, like all correlational findings, it is therefore possible that there are unmeasured third variables that explain our results. Similarly, based on the current study, we cannot make any causal claims. Indeed, Experiment 2 was unable to find a causal influence of belief in dualism and determinism on biological motion perception. While this might indicate that there is no causal relationship, it could also mean that the manipulation was not strong enough to have a downstream effect on biological motion perception. In this respect, it is important to note that the influence of the manipulation on free will beliefs, although reliable, is rather weak (Genschow et al., 2021). In addition, another concern with the manipulation used here (although widely used in the literature; Genschow et al., 2021) is that the control scenario might not have been optimal, as giving an introduction to consciousness might potentially prime participants that there is a non-physical entity that is separate from the body. This, in turn, could then increase belief in dualism. If anything, however, this should have made it more likely to find an effect of the manipulation. As a result, it cannot easily explain why we found no such effects. Instead, to definitively test whether there is a causal influence of belief in free will on biological motion detection, it will primarily be important to device stronger manipulations that are more likely to trigger downstream effects.

Finally, a last point of discussion is whether the effects reported here are specific to biological motion or whether people who believe in dualism/determinism are simply more likely to see patterns in noise. Detecting the presence of other agents is a crucial to survive and reproduce. As stated by Barrett (2004), human beings have evolved to be hyper-agency detectors. Such hyper-agency detection, in turn, has been argued to explain the human tendency to believe in the existence of invisible agents, such as spirits and angels, and in mind–body dualism (Bloom, 2005). These considerations suggest that the dualism associations reported here might be at least partly specific to biological motion detection. However, an important task for future research will be to investigate this more directly, for example, by investigating if pattern recognition in other contexts can explain the relationship between belief in dualism and the detection of biological motion.

Conclusion

In the current study, we wanted to investigate whether beliefs related to free will are associated with biological motion detection. In two experiments, we found that two beliefs related to free will, namely, belief in determinism and belief in dualism, were associated with the perception of biological motion. However, no causal relationship was found when experimentally manipulating free will-related beliefs. Nevertheless, our research broadens the perspective of top-down processing of social perception by demonstrating that free will-related beliefs are related to low-level social perceptual processes and decision making.

Appendix A

Text manipulation on free will beliefs

Introduction about Francis Crick

Francis Crick is the British physicist and biochemist who collaborated with James D. Watson in the discovery of the molecular structure of DNA, for which they received the Nobel Prize in 1962. [Here the following picture of Francis Crick accessed by Nobelprize.org (2014) Francis Crick—Facts. Nobel Media AB. (Available at www.nobelprize.org/nobel_prizes/medicine/laureates/ 1962/crick-facts.html. Accessed January 10, 2017) was inserted.] He is the author of What Mad Pursuit, Life Itself, and Of Molecules and Men. Dr. Crick lectures widely all over the world to both professional and lay audiences, and is a Distinguished Research Professor at The Salk Institute in La Jolla, CA. Dr. Crick's essay (next page) comes from The Astonishing Hypothesis: The Scientific Search for the Soul (44).

Text used in control group: the general nature of consciousness

Psychologists have shown that common sense ideas about the working of the mind can be misleading. When psychology began as an experimental science, in the latter part of the nineteenth century, there was much interest in consciousness. It was hoped that psychology might become more scientific by refining introspection until it became a reliable technique. Since the problem of consciousness is such a central one, and since consciousness appears so mysterious, one might have expected that psychologists and neuroscientists would now direct major efforts toward understanding it. This, however, is far from being the case. The majority of modern psychologists omit any mention of the problem, although much of what they study enters into consciousness. Most modern neuroscientists ignore it. The American psychologist, William James, discussed consciousness in his work "The Principles of Psychology" (1898), and described five properties of what he called "thought." Every thought, he wrote, tends to be part of personal consciousness. Thought is always changing, is sensibly continuous, and appears to deal with objects independent of itself. In addition, thought focuses on some objects to the exclusion of others. In other words, it involves attention. Of attention he wrote, "It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. It implies withdrawal from some things in order to deal effectively with others." Many psychologists believed that some processes are subliminal or subconscious. For example perception was similar in its logical structure to what we normally mean by inference, but that it was largely unconscious. Three basic ideas of consciousness were developed. Firstly, not all of the operations of the brain correspond to consciousness. Secondly, consciousness involves some form of memory, probably a very short term one. Thirdly, consciousness is closely associated with attention. Unfortunately, a movement arose in academic psychology that denied the usefulness of consciousness as a psychological concept. This was partly because experiments involving introspection (which involves thinking about what one is thinking) did not appear to be leading anywhere and partly because it was hoped that psychology could become more scientific by studying behavior that could be observed unambiguously by the experimenter. This was called the Behaviorist movement. It became taboo to talk about mental events. All behavior had to be explained in terms of the stimulus and the response. How can we approach the study of consciousness in a scientific manner? Consciousness takes many forms, but as I have already explained, for an initial scientific attack it usually pays to concentrate on the form that appears easiest to study. Christof Koch and I chose visual awareness rather than other forms of consciousness, such as pain or self-awareness, because humans are very visual animals and our visual input is especially vivid and rich in information. In addition, its input is often highly structured yet easy to control. For these reasons much experimental work has already been done on it.

Text used in anti-free will group: a postscript on free will

"You," your joys and your sorrows, your memories and your ambitions, your sense of personal identity and free will, are in fact no more than the behavior of a vast assembly of nerve cells and their associated molecules. Who you are is nothing but a pack of neurons. Most religions hold that some kind of spirit exists that persists after one's bodily death and, to some degree, embodies the essence of that human being. Religions may not have all of the same beliefs, but they do have a broad agreement that people have souls. However, the common belief of today has a totally different view. It is inclined to believe that the idea of a soul, distinct fromthe body and not subject to our known scientific laws, is a myth. It is quite understandable how this myth arose without today's scientific knowledge of nature of matter and radiation, and of biological evolution. Such myths, of having a soul, seem only too plausible. For example, four thousand years ago almost everyone believed the earth was flat. Only with modern science has it occurred to us that in fact the earth is round. From modern science we now know that all living things, from bacteria to ourselves, are closely related at the biochemical level. We now know that many species of plants and animals have evolved over time. We can watch the basic processes of evolution happening today, both in the field and in our test tubes and therefore, there is no need for the religious concept of a soul to explain the behavior of humans and other animals. In addition to scientists, many educated people also share the belief that the soul is a metaphor and that there is no personal life either before conception or after death. Most people take free will for granted, since they feel that usually they are free to act as they please. Three assumptions can be made about free will. The first assumption is that part of one's brain is concerned with making plans for future actions, without necessarily carrying them out. The second assumption is that one is not conscious of the "computations" done by this part of the brain but only of the "decisions" it makes—that is, its plans, depending of course on its current inputs from other parts of the brain. The third assumption is that the decision to act on one's plan or another is also subject to the same limitations in that one has immediate recall of what is decided, but not of the computations that went into the decision. So, although we appear to have free will, in fact, our choices have already been predetermined for us and we cannot change that. The actual cause of the decisionmay be clear cut or it may be determined by chaos, that is, a very small perturbation maymake a big difference to the end result. This would give the appearance of the Will being "free" since it would make the outcome essentially unpredictable. Of course, conscious activities may also influence the decision mechanism. One's self can attempt to explain why it made a certain choice. Sometimes we may reach the correct conclusion. At other times, we will either not know or, more likely, will confabulate, because there is no conscious knowledge of the "reason" for the choice. This implies that there must be a mechanism for confabulation, meaning that given a certain amount of evidence, which may or may not be misleading, part of the brain will jump to the simplest conclusion.

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Availability of data and material Not applicable.

Code availability Not applicable.

Declarations

Conflict of interest Wei Peng declares that he has no conflict of interest. Emiel Cracco declares that he has no conflict of interest. Nikolaus F. Troje declares that he has no conflict of interest. Marcel Brass declares that he has no conflict of interest.

Ethics approval All procedures performed in studies involving human participants were in accordance with the ethical standards of Ghent University and local research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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