

Functional and Proximal Mechanisms of Effort Matching in Joint Action

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Declaration of Authorship

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, or which have been accepted for the award of any other degree or diploma at Central European University or any other educational institution, except where due acknowledgement is made in the form of bibliographical reference.

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Abstract

Human life is woven through joint action. We organize governments, run businesses, conduct research projects, co-parent children and create music together. In recent years, considerable research has been devoted to investigating the psychological mechanisms which support this. One key finding is that people frequently calibrate their effort level to match a joint action partner's effort - but it is not clear why they do so. In this dissertation, I aim to clarify a fundamental question: Why do people match their joint action partners' effort? Specifically, I ask why evolution would have equipped us with such a tendency, and what the proximate psychological mechanisms are that underpin it.

Across Chapters 2-5, I present a range of empirical studies that bear upon these questions. In Chapter 2, I address a prerequisite condition for effort matching. In particular, in order to calibrate our effort to that of others, we need to have the capacity to estimate the effort costs that observed agents are currently investing in specific ongoing activities. Therefore, in Chapter 2, I identify some of the relevant factors that feed into adults' judgments about the level of others' effort. Then, in Chapters 3-4, I investigate a battery of hypotheses about the evolutionary functions which may explain why people match their joint action partners' effort, as well as a battery of hypotheses about the proximate psychological mechanisms underpinning this behavior. Finally, in Chapter 5, I investigate the extent to which insights gained from research investigating how people distribute rewards can be generalized to scenarios in which people make decisions about how to distribute effort costs.

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**I dedicate this dissertation
to my wife, Gitta,
and to my daughter, Zselyke.**

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Chapter 1. Introduction

Human life is woven through joint action. We organize governments, run businesses, conduct research projects, co-parent children and create music together. In doing so, we generate an enormous amount of surplus benefit that would not be possible to obtain individually, and we distribute the benefits produced by collaboration among interested parties. To achieve this, we first of all require a battery of cognitive mechanisms enabling us to coordinate our decisions and actions with each other, as well as motivational mechanisms enabling us to work together. Second, we require a battery of cognitive and motivational mechanisms enabling us to distribute the benefits in ways that sustain cooperation in the long term. In recent decades, research in many areas has addressed these aspects of our proclivity for cooperation. Behavioral economics and neuroeconomics have examined people's willingness and motivation to cooperate; cognitive psychology and social neuroscience have explored the mechanisms enabling people to coordinate their decisions and to engage in joint action; while developmental and comparative psychology have illuminated the ontogenetic and phylogenetic emergence of cooperative behavior.

In particular, a great deal of research has been devoted to investigating how people distribute the outcomes of cooperative endeavors. A large body of work shows that 3-year-old children and adults distribute rewards according to work input when they work together to obtain the rewards (Cappelen et al., 2007; Frohlich et al., 2004; Hamann et al., 2014; Kanngiesser & Warneken, 2012). The starting point of the present dissertation is that, in spite of the large body of work on how people distribute the outcomes of cooperative endeavors, there is one key aspect that remains to be explored. Specifically, the challenge of determining how to distribute the benefits of cooperation in the right way (whatever that is) is preceded by

the equally important challenge of deciding how to distribute effort¹ costs – i.e., *how the parties to the joint action should calibrate their effort investment*. Calibrating effort investment is especially important if you consider that cooperative endeavors do not necessarily produce any distributable results. One reason for this is that the success of cooperative endeavors is always at least to some extent uncertain. Like individual endeavors, they may not succeed because of exogenous factors or lack of competence. In addition, they may not succeed because the collaborative partner may encounter a tempting outside option and so may prematurely withdraw from the joint activity. Moreover, even if a joint activity yields a reward, this reward may not be divisible - e.g., co-parenting or tidying up together may not produce any divisible reward at all. In such activities, there is nothing to distribute at the end, but it is still possible to distribute the effort costs. Thus, in our day-to-day cooperative interactions calibrating effort investment appears to be an important way to distribute the costs and benefits of cooperation.

To investigate this conjecture, I will draw on joint action research. Research on joint action builds on Sebanz et al.'s seminal 2006 paper, which defined joint action as “any form of social interaction whereby two or more individuals coordinate their actions in space and time to bring about a change in the environment” (p. 70), such as making love or carrying a sofa together. This research has established that when people act together for a shared goal, they represent each other's actions and tasks, and also the constraints on others' task performance (Atmaca et al., 2008, Kourtis et al., 2014; Schmitz et al., 2017; Vesper et al., 2013). Building on these capacities, people coordinate their actions with each other by

¹ Within the context of this dissertation, I conceptualize effort as the deployment of some resource (e.g., metabolic resources or computational capacity) to reach some goal. It is important to note that my conception of effort includes the possibility that people may achieve the same goal or perform the same action with different levels of effort because they have different abilities. For a review of the ongoing debate on how to conceptualize effort, see Massin (2017).

monitoring and predicting each other's actions (Sebanz & Knoblich, 2009; Loher et al., 2013; Vesper et al., 2010; Wolf et al., 2018), and they sometimes communicate through action by deviating from the most efficient way to perform the task (Pezzulo et al., 2013; McEllin et al., 2018; Vesper et al., 2017).

How do individuals decide whether to engage and persist in joint action, and how vigorously to contribute to ongoing joint action? These questions have begun to receive increasing attention recently. In particular, Michael et al. (2016a) began to address this shortcoming by introducing a comprehensive framework to investigate the cognitive and motivational processes underpinning people's sense of commitment to performing actions together. This framework identifies various situational factors, such as the perception of others' effort, coordination and repetition that boost one's willingness to persist and invest effort in a joint action. Subsequent research has found empirical evidence for these hypotheses: participants persisted for longer on an effortful task in a high perceived effort condition than in a low perceived effort condition (Székely & Michael, 2018; Chennells & Michael, 2018), participants judged others to persist and be more likely to resist a tempting outside option in a high coordination condition than in a low coordination condition (Michael et al., 2016b), and participants were more likely to resist a tempting outside option when a coordination task was repeated with the same partner than when it was repeated with different partners (Chennells et al., 2022). Moreover, Michael (2022) put forward a conjecture suggesting that what these factors have in common is that they all provide evidence of a partner's effort investment indicative of a partner's expectation and reliance. Taken together, this research suggests that one's effort investment boosts one's partner's willingness to persist and invest effort in a joint action.

An important next step would be to investigate why evolution would have equipped us with such a tendency, and what the proximate psychological mechanisms are which

underpin it. Using this recent research as a platform, the present dissertation contributes to these questions by bringing joint action research in connection with evolutionary theories of cooperation.

Research in evolutionary theory has identified various evolutionary mechanisms that make cooperative interactions stable - i.e. mechanisms under which natural selection can lead to cooperation - such as kin selection, direct and indirect reciprocity and group selection (Nowak, 2006). These evolutionary mechanisms generate selection pressure that favors psychological adaptations underpinning cooperation such as other-regarding (Charness & Rabin, 2002) and mind-directed preferences (Heintz et al., 2015), a preference for acting together (Carr & Walton, 2014) and capacities for reputation management (Barclay, 2013).

Most of the empirical studies investigating the evolutionary origins and motivational mechanisms to cooperate have focused on the exchange of rewards (e.g., monetary resources), and their results are used to support claims about humans' willingness and motivation to cooperate more generally. As Bars et al. (2022) have recently pointed out, an important new challenge is to explore the interplay between high-level, strategic decision-making and low-level motor processes. Taking up this challenge, the present dissertation assesses humans' decision-making processes with regard to sharing the costs and benefits of cooperation in the context of joint action - where the main and ever-present resource at stake is *effort*.

Building on and creating synergies between these two different strands of research (cognitive mechanisms underpinning joint action and motivational mechanisms underpinning cooperation), I aim to clarify a fundamental question: *Why do people match their partner's effort?* That is, people (at least sometimes) calibrate their own effort investment in the direction of that of a joint action partner (Székely & Michael, 2018; Chennells & Michael,

2018), however, it is not clear why they do so. I ask why evolution would have equipped us with such a tendency, and what the proximate psychological mechanisms are that underpin it.

Across Chapters 2-5, I present a range of empirical studies that bear upon these questions. The first step (Chapter 2) is to address a prerequisite condition. In particular, in order to calibrate our efforts to that of others, we need to be able to perceive others' effort - i.e. we need to have the capacity to estimate the effort costs that observed agents are currently investing in specific ongoing activities. Therefore, in Chapter 2, I will identify some of the relevant factors that feed into adults' judgments about the level of others' effort. In doing so, I will draw upon and contribute to previous research which, though not investigating how people perceive others' effort directly, does provide a valuable platform to build upon. Then, in Chapters 3-4, I will investigate a battery of hypotheses about the evolutionary functions which may explain why people match their partner's effort, as well as a battery of hypotheses about the proximate psychological mechanisms underpinning this behavior. Finally, in Chapter 5, I will investigate the extent to which insights gained from research investigating how people distribute rewards can be generalized to scenarios in which people make decisions about how to distribute effort costs. In the following, I will briefly sketch the theoretical basis of the empirical work presented in Chapter 2-5.

Perceiving Others' Effort Costs (Chapter 2)

There has been some research investigating the perception of others' effort -- which should come as no surprise given that the perception of others' effort is a ubiquitous feature of everyday life. This research has suggested that humans continuously track others' effort investment (Apps et al., 2016), and do so quite accurately (Liang et al., 2019), especially when the stakes are high (Ibbotson et al., 2019). However, to the best of our knowledge, researchers have not explicitly addressed the mechanisms underpinning people's capacity to estimate other's effort costs. Thus, little is known about what kind of information people draw upon in order to do so.

What is known comes from research, in which researchers did not investigate the mechanisms of effort perception directly, but in which researchers investigated the inferences and responses that children and adults make when perceiving others' effort. In so doing, researchers deployed a diverse range of effort cues and their results suggest that people draw upon diverse sources of information to perceive others' effort. For example, Liu et al. (2017) investigated whether infants are sensitive to the effort costs of others' actions, and whether they can integrate the costs and benefits of others' actions to predict others' goals. The effort costs were conveyed through different physical path features of actions, such as height, width, and incline angle, whose magnitude indicated the level of effort an agent must exert. They found that infants, after seeing an agent attaining two goals equally often at varying effort costs, expected the agent to prefer the goal she attained through more effortful actions. This implies that infants make appropriate effort assessments when the effortfulness of others' actions is systematically varied through physical properties of actions. In another study, Ibbotson et al. (2019) investigated the accuracy of adults' perception of effort. Participants had to move balls into a bucket by pushing them up a ramp through mouse clicks while their partner was doing the same task as them. At the end of each trial participants had

to decide whether they put in more or less effort than their partner. The effort costs were conveyed through the relative frequency that the balls were being pushed up the ramp. The authors found that participants correctly judged who was putting in more or less effort 78.6% of the time, and they were more accurate when their partner was a slacker or when they put in more effort themselves. In addition, in other studies researchers have deployed a diverse combination of effort cues simultaneously. For example, Jara-Ettinger et al. (2015) probed whether 5-6 years old children take agents' effort costs into account in order to accurately infer their preferences. In their first experiment, children observed a puppet climbing a short box swiftly and nodding in agreement (low effort cost condition), or climbing a tall box slowly and running out of breath (high effort cost condition). Then the puppet had to choose between two treats (banana and watermelon) that were placed on the short box - the puppet chose the banana. Next, the experimenter placed the watermelon on the short box and the banana on the tall box - this time the puppet chose the watermelon. Even though the puppet had chosen both treats exactly once, when the experimenter asked which treat the puppet liked the most, children successfully identified the puppet's preferred treat as the banana, indicating that they were sensitive to the relative costs of her choices. The authors suggested that their findings show that children can integrate the effort costs of climbing the tall and short box with the agent's actions to infer the agent's preferences. Noteworthy, the effort costs were conveyed through a diverse combination of effort cues: facial cues ("nodding"), properties of movement trajectory (height of the box) and cues generated by the increased activity of the sympathetic nervous system ("running out of breath"). Taken together, these studies reveal that people draw upon diverse sources of information to perceive others' effort.

These preliminary observations motivate the introduction of three (mutually compatible) hypotheses about the sources of information and mechanisms operating on them that may enable us to perceive others' effort. One possibility is that people estimate others' effort costs by tracking certain features of movement such as path length, speed or time. Because greater magnitude in dimensions such as path length, speed or time typically corresponds to greater outlays of energy, people may expect the magnitude of these cues to be correlated with effort costs. Alternatively, one may speculate that people estimate others' effort costs by tracking perceptible properties of others' autonomic nervous system such as breathing patterns and cues of muscle tension because cues to the level of activity of the autonomic nervous system convey information about the current level of effort investment (Rejeski & Lowe, 1980; de Morree & Marcora, 2010; Liu et al., 2017). Finally, building on results suggesting that during observation of an action, a corresponding representation in the observer's cortical motor system is activated (Rizzolatti & Craighero, 2004; Frith & Singer, 2008) - people may perceive others' effort through their own motor system. These possible mechanisms are not mutually exclusive, and they may be distinct but complementary mechanisms to estimate others' effort costs.

Among these hypotheses about the sources of information and mechanisms of effort perception, the most prevalent assumption in the literature is that people use movement features as a proxy for estimating others' effort costs. And indeed, this assumption has been fruitfully adopted in some important research in developmental psychology (Verschoor & Biro, 2012; Csibra, 2008; Southgate & Csibra, 2008; Kamewari et al., 2005; Csibra et al., 2003; Csibra et al., 1999; Woodward, 1998; Gergely et al., 1995). However, it must be acknowledged that it has yet to be directly tested and it has not been investigated in relation to cognitive effort perception.

To address this gap in the literature, in Chapter 2, I tested whether adults estimate others' cognitive effort costs by tracking perceptible properties of movement such as path length, speed or time. I hypothesized that because greater magnitude in dimensions such as path length, speed or time typically corresponds to greater outlays of energy, people expect the magnitude of these cues to be correlated with effort costs. In the task, participants viewed videos in which stars progressively appeared to indicate that a partner was solving a captcha², and then they were asked how much effort they thought it had taken the partner to solve this captcha. Participants estimated others' effort costs of deciphering a captcha on a Likert scale (1-7). I analyzed their decisions in two experiments.

Chapter 2 contributes to previous research in several ways. First, it provides a test of assumptions about effort perception made by a large body of work using movement cues as a basis for effort perception. In addition, I tested whether the principles gained from experiments implementing physical effort costs can be extended to situations in which adults have the task to perceive *cognitive effort* through movement cues. To my knowledge, the experiments reported here are the first to directly test how adults perceive others' cognitive effort costs.

Beyond its direct contribution to the literature, the results of Chapter 2 helped me to design and implement appropriate stimuli for the experiments in Chapter 4. In particular, by identifying the relevant factors that feed into adult's judgment about the level of others' effort, I made sure that participants in the experiments register systematic differences when observing their partner's effort investment. This enabled me to examine how the perception of the partner's effort modulates effort-based decision-making in joint action.

² A captcha is a type of cognitive task that is intended to distinguish human from machine input and people frequently encounter them on online platforms. I used text-based captchas with various numbers of characters as examples for the task.

Evolutionary Functions and Mechanisms of Effort Matching (Chapters 3-4)

Why would the perception of a partner's effort modulate one's effort investment? Clearly, most cooperative tasks require people to monitor their partner's effort investment and regulate their own effort investments with this information at hand in relation to the joint goal. For example, imagine that we are lifting a sofa together and I notice that we are investing a lower level of effort than it would be needed to lift off the sofa. This may prompt me to abruptly increase my efforts to jointly lift it off. As we are jointly holding the sofa, I may notice that gradually you also increase your level of effort and so I can decrease mine. In these ways, we calibrate our effort investments in order to exert sufficient force to hold the sofa above the ground. Alternatively, it may happen that my position allows me to get a better grasp on the sofa than you, such that my effort investments are more efficient; if so, I may choose to minimize our joint effort by increasing the level of my effort and decreasing yours. This would allow us to act rationally as a dyad - and there is evidence that people have a preference for this (Török et al., 2019). Alternatively, it may happen that as we are carrying the sofa together, I notice that you are investing a higher level of effort than me; if so, this may prompt me to increase my efforts. Or it may happen that as we are carrying the sofa together, I notice that you are investing a lower level of effort than me; if so, this may prompt me to decrease my efforts. I will call this pattern of effort calibration as effort matching - in which I calibrate my level of effort investment in the direction to that of yours – and this has been documented by multiple studies (e.g., Székely & Michael, 2018; Chennells & Michael, 2018). However, these studies did not resolve the question as to *why* people (at least sometimes) do so.

If we systematically adapt our own effort investment in the direction of that of a joint action partner, then what functions would this serve? In theorizing about the potential functions of effort matching, we may begin from the observation that agents may utilize

others' effort to optimize their effort investment to the relationship with the other agent (*relationship-directed effort calibration*) or to the environment (*environment-directed effort calibration*). In the following, I will spell out these ideas and formulate distinct hypotheses about the evolutionary functions of effort matching and the proximal psychological mechanisms that may underpin them.

Relationship-Directed Effort Calibration

Cooperative interactions by themselves are unstable: without any mechanism for stabilizing cooperation, natural selection favors defectors and constantly reduces the number of cooperators in a population (Nowak, 2006). In order to stabilize cooperation, various mechanisms are at work, such as kin selection, direct and indirect reciprocity and group selection (Hamilton, 1964; Trivers, 1971; Nowak & Sigmund, 1998; Traulsen & Nowak, 2006). In addition, when organisms can control who they interact with, natural selection favors organisms that spend more time with partners who confer upon them the greatest fitness benefits (Noë and Hammerstein, 1994, 1995). This means that when individuals can choose partners, there is selection pressure favoring psychological adaptations for choosing, attracting and maintaining good collaboration partners (Barclay, 2013).

Accordingly, there is a growing body of evidence that people tend to be more generous in order to attract better partners and correspondingly they choose the most generous individuals. For example, Barclay & Willer (2007), in a series of lab-based experiments, probed whether participants give more to increase the probability of being chosen. They found that people donated more money when they could benefit from being chosen for cooperative partnerships, and the most generous people were indeed chosen more often as cooperative partners. Similarly, Gurven (2004), reviewing field observations of contemporary hunter-gatherers, found that people choose their partners on the basis of their

willingness to share food. In addition, evidence shows that people are sensitive to facial cues to the long-term value of a potential partner, and distribute resources accordingly – e.g. being more generous towards other individuals whose appearance indicates health, attractiveness and prosociality (Eisenbruch et al., 2016). In sum, other things being equal, people's decision-making processes about the distribution of benefits reflects the ultimate goal of attracting and keeping good collaboration partners.

With this in mind, one may speculate that the psychological mechanisms that guide people's investment of effort in collaborative ventures may have been under similar selection pressure as the psychological mechanisms that guide the distribution of benefits. Specifically, we hypothesize that people may calibrate their effort investment in joint action with the ultimate goal of attracting and keeping good collaboration partners (*The relationship-directed effort calibration hypothesis*). As a consequence, we should expect that this is reflected at the level of proximate psychological mechanisms that determine how people exert effort.

If it is true that people tend to calibrate their effort investment in joint action with this ultimate goal, what might the proximal psychological motives be that drive them to do so? One possibility is linked to the idea of fairness. A growing body of theoretical and empirical work suggests that our sense of fairness implies a preference for divisions of rewards that are proportional to contributions (André & Baumard, 2011; Baumard et al., 2013; Debove et al., 2015; Debove et al., 2017; Frohlich et al., 2004; Hamann et al., 2014; Kanngiesser & Warneken, 2012). This research has established that people are highly sensitive to the distribution of effort costs and that reward distribution is governed by a sense of fairness which takes effort investments into account. For example, Frohlich et al. (2004) found that when participants were placed in one room and had to proofread a text to correct spelling errors for joint rewards, they divided their collectively earned rewards proportionally to

individual effort costs in a subsequent dictator game. Similarly, recent studies have shown that three-year old children (but not 2-year-olds) take effort costs into account to achieve a fair distribution of joint action outcomes (Hamann et al., 2014; Kanngiesser & Warneken, 2012). In addition, Sloane et al. (2012) found that even 21-month-olds infants expected an experimenter to distribute rewards among two individuals proportional to their effort costs. Extending these results, one may hypothesize that the sense of fairness leads people not only to distribute resources according to individual effort costs but to distribute effort costs according to the expected reward distribution as well.

Such a tendency would be important because, as noted earlier, the success of cooperative endeavors is always at least to some extent uncertain. Like individual endeavors, they may not succeed because of exogenous factors or lack of competence. In addition, they may not succeed because the collaborative partner may encounter a tempting outside option and so may prematurely withdraw from the joint activity. For these reasons, for example, hunting and foraging in ancestral environments were uncertain endeavors, and they may not have yielded any reward to distribute at all. Moreover, even if a joint activity yields a reward, this reward may not be divisible - e.g., co-parenting or tidying up together may not produce any divisible reward. In such instances, the only way to share the costs and benefits of a joint action fairly is to invest effort equally.

Taken together, this line of reasoning leads us to the following hypothesis about the proximal psychological mechanism that motivate people to calibrate their effort investment in joint action with the ultimate goal of maintaining collaborative relationships with valuable partners: we should expect joint action partners to ensure fairness by calibrating their effort investment such as to reduce inequity with respect to joint action partners' effort investment (*The equity through effort calibration hypothesis*).

Environment-Directed Effort Calibration

Another candidate evolutionary function of social effort calibration arises from the fact that sometimes the value of opportunities afforded by the environment is uncertain or not known. Because adaptively selecting the course of action associated with the highest utility requires one to weigh potential rewards against anticipated costs - in such circumstances, one may use others' investment of effort to infer the reward value they anticipate for their similar action plan. For example, if the partner is pursuing a high-cost plan of action, one can confidently infer that the partner expects a high reward from that plan. Accordingly, people may use their partner's effort costs as information to infer the value of opportunities afforded by their environment, which may lead them to adjust their effort investment as a function of the inferred value (*The environment-directed effort calibration hypothesis*).

This hypothesis gains credence from a range of previous research at the level of proximate psychological mechanism. In particular, decades of work on social referencing have shown that people routinely use others' facial expressions, postures and actions as a source of information to determine which course of action is worth pursuing (Leonard et al., 2017; Egyed et al., 2013; Parkinson et al., 2012; Sorce et al., 1985; Darley & Latané, 1968). For example, Leonard et al. (2017) found that infants who observed a couple of examples of an adult working hard to achieve her goals persisted longer on a novel task than those who observed an adult succeed effortlessly. Moreover, our hypothesis builds on recent theoretical and empirical work on the naïve utility calculus suggesting that people assume that other agents act to maximize subjective utility and by building on this assumption, they competently make a vast array of inferences even at the age of 10 months (Baker et al., 2017; Jara-Ettinger, Gweon, Schulz & Tenenbaum, 2016; Jara-Ettinger, Gweon, Tenenbaum & Schulz, 2015; Liu et al., 2017). Taken together, these results lend support to the hypothesis

that people may use their partner's effort costs as information to determine which course of action is worth pursuing.

Putting These Hypotheses to the Test

To experimentally test the hypotheses generated by the theoretical analysis of the potential functions and mechanisms of effort matching, I designed a series of experiments.

In Chapter 3, I investigated why people match their joint action partner's effort . I hypothesized that people calibrate their effort investment in joint action with the ultimate goal of attracting and keeping good collaboration partners (The relationship-directed effort calibration hypothesis) and that the proximal psychological motive that drives them to do so is a preference for fairness (The equity through effort calibration hypothesis). Across three experiments, I tested these hypotheses and differentiated them from alternative explanations of why people match their partners' effort such as the environment-directed effort calibration hypothesis. In the task, participants had to repeatedly press a button to reach a target in order to obtain an unknown reward (1 or 5 points). Critically, the target was invisible and participants had to decide how long to persist before quitting. Before their turn, they observed as their partner performed the same task. Importantly, at the beginning of the trial, the reward value was only revealed to their partners. By manipulating the perceived effort of their partner, and participants' beliefs about the reward structure of the task (whether the reward structure of the task was the same/opposite for them and their partner or it was uncertain), I was able to investigate how participants used the perception of their partner's effort investment in their decision-making about how much effort to invest, and to implement scenarios across the three experiments in which the hypotheses sketched above lead to contrasting predictions.

Using this experimental design, Chapter 3 offers the first evidence for functional explanations of why people calibrate their own effort investment in the direction to that of a joint action partner and thereby contributes to attaining a fuller understanding of the role of effort and effort perception in human cooperative interactions. In addition, Chapter 3 provides a valuable addition to existing research on the sense of fairness.

In Chapter 4, I further investigated why people match their joint action partner's effort. I hypothesized that when people expect to share the reward of the joint task equally, they would ensure fairness by calibrating their effort investment such as to reduce inequity with respect to joint action partners' effort investment. To test this, I developed a task in which participants observed as their partner performed a cognitive effort task and then they traded off physical effort costs against reward. I manipulated whether the reward structure was joint or separate, and whether the available reward was known or unknown. This enabled me to create scenarios in which I can test the aforementioned hypothesis and differentiate it from alternative explanations. I analyzed their decisions in two experiments.

Chapter 4 extended the investigation of the functions and mechanisms of effort matching by two important ways. First, in Chapter 4, participants and their partner contributed *different kinds of effort in different ways* (the partner's effort was operationalized as the cognitive effort of deciphering a captcha, and participants' effort was operationalized as the physical effort investment of repeated key presses). This is in contrast to Chapter 3, where participants and their partner contributed *the same kind of effort in the same way* (both the partner's effort and participants' effort were operationalized as the physical effort investment of repeated key presses). This enabled me to generalize the findings of Chapter 3 by showing that participants are able to compare different kinds of effort and to adjust to their partner's effort accordingly. Second, the decision-making processes underpinning the

exertion of effort relate to different phases of behavior: first, one must decide whether one is willing to exert the anticipated effort costs (“Is it worth it?”), and then one must decide to what extent one’s action should be energized in order to achieve the desired results (“Should I persist?”) (Heron, Apps, Husain; 2018). While in Chapter 3 we measured participants’ willingness to invest effort in the process of investing effort, i.e., in the phase of “Should I persist?”; in Chapter 4 we measured participants’ willingness to invest effort when they decided whether they were willing to exert the anticipated effort costs, i.e., in the phase of “Is it worth it?”. This enabled me to generalize the findings of Chapter 3 by showing that participants calibrate their own effort investment in the direction of that of a joint action partner in both phases of behavior.

Distributing Costs and Benefits: Are Sharing Behaviors Resource-Specific? (Chapter 5)

Chapter 3 and 4 provided evidence that people have a preference for equitable distribution in production just as they have a preference for equitable distribution after resources have been created. This provides reasons to think that insights gained from research investigating how people distribute rewards can be generalized to scenarios in which people make decisions about how to distribute effort costs (*The resource-general hypothesis*). For example, people may be strategically motivated to share effort fairly -- similarly to their strategic motivation to share money fairly; and if so, participants’ decisions about resource allocation should depend on the expectations of reciprocity.

This is important insofar as it provides a crucial test of a (very reasonable and pragmatic assumption) made by most research in behavioral economics and psychological game theory -- although research homes in on money as the critical resource to be gained, lost, and distributed, the aim in doing so is to illuminate how people make decisions with regard to gaining, losing, and distributing resources more generally. And indeed, effort is a highly ubiquitous and important resource in everyday life now, as it has been throughout

evolutionary history. Thus, if insights gained from research using monetary rewards can successfully be extended to contexts involving effort, it would provide a powerful vindication of previous research in behavioral economics and psychological game theory, and by the same token demonstrate how joint action research can benefit from the insights, constraints and methods from these complementary strands of research on decision-making.

However, there are also reasons to think that there are important differences. In particular, the allocation of effort may engage more intrinsic cooperative motivations than decisions about the allocation of already produced benefits. For example, Baumard, André and Sperber (2013) argue for an account of the evolution of fairness in which competition among cooperative partners leads people to strategically share the costs and rewards of cooperation equally. With time, however, this eventually leads to the selection of a disposition to be intrinsically motivated to cooperate fairly. This is so because, at the psychological level, this may be a more cost-effective way of securing a good collaborative reputation than constantly engaging in the cost-benefit analyses of the implications of various sharing behaviors. If so, we should expect that the cost-effectiveness of strategic or intrinsic sharing behavior should depend on the resource type. In particular, we may expect higher levels of intrinsic sharing behavior with respect to resources that are most prevalent in interactions. For example, cooperative interactions always involve effort costs but don't necessarily involve any distributable reward. If so, then scenarios requiring decisions about how to allocate effort may engage more robust intrinsic cooperative motivations. Specifically, while the need to allocate money may only weakly trigger an intrinsic motivation to cooperate fairly, the need to allocate effort may do so more strongly (*The resource-specific hypothesis*).

If we make comparisons across studies and populations, then existing experimental evidence suggests that there may be greater generosity in the context of effort costs than in

the context of monetary rewards. In a labor allocation experiment, (Güth, 1984, as cited in Güth & Brandstätter, 1994, p. 166). asked pairs of participants to solve 12 tables of complex multiplication tasks for equal rewards. One member of each pair had the role of allocating the tables of multiplication tasks between them, and had a calculator, while their partner had to accept the task which was allocated to them and did not have a calculator. Only 5 of 62 participants allocated all the work to their partner, whereas the rest of participants tried to allocate the work in such a way that both them and their partner would end up investing equal work time (that is, allocators assigned to themselves around 9 to 12 tables of the 12 tables). This means that only 8.06% of all participants chose allocations that were maximally selfish. These results are in contrast with dictator games where the allocated resource is monetary. Engel (2011) conducted a meta-analysis on the results of 131 dictator games; he found that on average 36.11% of all participants chose allocations that were maximally selfish - that is, they gave nothing to the recipient. Thus, this pattern of findings provides reason to suspect that there may be greater generosity in the context of effort costs than in the context of monetary rewards.

In Chapter 5, we hypothesized that people are strategically motivated to share effort fairly, i.e., we predicted that people would share effort more fairly when there is an expectation of reciprocity – similarly to their strategic motivation to share money more fairly when there is an expectation of reciprocity. In addition, we also hypothesized that decisions about the allocation of effort are shaped by more robust intrinsic preference for fair distributions than decisions about the allocation of money. To test these hypotheses, we carried out four pre-registered online experiments implementing a one-shot, anonymous dictator game. By manipulating resource type, expectation of reciprocity, decision time, stake size and perceived legitimacy, we created scenarios in which we could compare and contrast

how people distribute effort costs and rewards. We analyzed how participants distributed resources (money or effort) between themselves and another player.

Chapter 5 contributes to previous research in two ways. First, it extends some crucial findings in the context of decision-making about monetary rewards to the context of decision-making about effort. Second, it provides the first empirical test of the conjecture that people may have a more robust intrinsic motivation to share effort fairly than money.

Chapter 2. Perceiving Others' Effort Through Movement Cues: Path length, Speed and Time

Effort perception - i.e. the capacity to estimate the effort costs that observed agents are investing in specific ongoing activities – is a crucial capacity underpinning characteristically human forms of sociality. Effort perception enables one to estimate to what extent other agents prioritize the goals they are currently pursuing, and accordingly to anticipate their future decisions and actions. In addition, for highly cooperative species such as humans, effort perception is particularly important insofar as it provides a key input for inferences about fairness, e.g. enabling us to calibrate our own effort contribution to match the effort contributions of a partner. Indeed, effort perception may prompt one to decrease one's own effort investment to avoid being exploited, or to increase one's effort investment in order to ensure an equal or fair distribution of effort costs. Moreover, accurate effort perception may also play an important supporting role in social learning: by estimating to what extent others prioritize particular goals, we can draw inferences about the value that those goals may have for us, irrespective of whether we pursue them jointly or individually.

In view of the functional advantages to be gained from accurately assessing the amount of effort that others are investing in specific activities, it is no surprise that humans continuously track others' effort investment (Apps, Rushworth & Chang, 2016), and do so quite accurately (Liang et al., 2019), especially when the stakes are high (Ibbotson, Hauert, & Walker, 2019). Indeed, research by Gergely and Csibra (2003) shows that even infants as young as 12-months-old rely on information about agents' effort costs to infer those agents' goals and to predict their actions, and Liu et al. (2017) found that infants take agents' effort costs into account in order to infer their preferences. Likewise, some recent research has documented the effects of effort perception upon adults' and even infants' willingness to invest effort. For example, Székely & Michael (2018) found that adult participants persisted

longer on an effortful task when they had perceived a partner investing a high level of effort than when they had perceived the partner investing a low level of effort (cf. Chennells & Michael, 2018; Jackson & Harkins, 1985). Extending these results, Székely & Michael (2022) found that adults chose to invest more or less effort to reduce inequity with respect to joint action partners' effort investment. In the developmental literature, Leonard et al. (2017) reported that infants who observed a demonstration of an adult working hard to achieve her goal persisted longer on a novel task than infants who observed the adult succeed effortlessly.

Despite the crucial importance and prevalence of effort perception, little is known about the mechanisms underpinning it. One may speculate that we assess others' effort costs by simple heuristics based on perceptible properties of their actions. Specifically, greater magnitude in dimensions such as path length, time or speed may indicate greater effort costs. The rationale for this is that greater magnitudes along these dimensions typically co-vary with greater outlays of energy and may therefore be expected to be correlated with higher effort investment. Thus, by tracking such perceptible properties of actions, perceivers may be able to access information about the current effort investments of observed agents. And indeed, this assumption has been fruitfully adopted in some important research in developmental psychology (Verschoor & Biro, 2012; Csibra, 2008; Southgate & Csibra, 2008; Kamewari et al., 2005; Csibra et al., 2003; Csibra et al., 1999; Woodward, 1998; Gergely, Nádasdy, Csibra & Bíró, 1995) – although it must be acknowledged that it has yet to be directly tested, and has not been investigated in relation to adult effort perception.

In the current study, we tested whether adults estimate others' effort costs by tracking perceptible properties of actions. In particular, we hypothesized that people expect path length, time and speed to be positively correlated with effort costs because greater magnitude in dimensions such as path length, time and speed typically correspond to greater outlays of energy. To test this, we implemented an effort perception task in two experiments. It is

important to note that path length, time and speed are necessarily confounded: it is impossible to simultaneously manipulate path length, time and speed independently because speed is a linear combination of path length and time. Therefore, in the first experiment, we manipulated path length separately and speed/time together; while in the second experiment we manipulated time separately and speed/path length together. This strategy enabled us to tease apart the relative contributions of each of these factors to effort perception.

Experiment 1

To test whether people estimate others' effort costs by tracking the speed or path length of an action, we implemented an effort perception task. In this task, participants were told that they would view recordings of a partner solving captchas. On each trial, a video was presented to them in which stars progressively appeared to indicate that the partner was solving a captcha, and then they were asked how much effort they thought it had taken the partner to solve this captcha. Participants estimated others' effort costs of deciphering a captcha on a Likert scale (1-7).

In a within-subject design experiment, we manipulated the process of deciphering the captcha by two factors: Length and Speed/Time. We manipulated Length by modifying the number of steps (characters) it takes to solve the captcha. There were four levels of captcha path length: 3, 6, 10 and 12 steps. In addition, we manipulated the Speed/Time at which these steps were taken. Captchas with equal length were completed faster, in shorter time in the Fast condition than in the Slow condition.

This design enabled us to investigate whether participants estimate others' effort costs by tracking the path length and speed/time of an action. We predicted a main effect of Length – that is, we expected participants to estimate others' effort costs in deciphering a captcha as higher when there were more steps. Moreover, we predicted a main effect of Speed/Time. Specifically, we predicted that if participants track speed then they should estimate others'

effort costs in deciphering a captcha as higher when it was completed more quickly; or alternatively, if participants track time, then they should estimate others' effort costs in deciphering a captcha as higher when it was completed slower.

Method

Participants. We expected a medium effect size based on pilot results, and therefore our target sample was 200 participants. Due to a technical error, we collected data from 298 participants. Of these, 39 individuals were excluded from analyses because they did not complete the task or failed 2 of 3 comprehension check questions, leaving a sample of 259 (i.e. 259 participants: 119 female, 3 other, 1 prefer not to say, $M_{age} = 28.88$ years, $SD_{age} = 9.3$ years) participants in the final dataset. All participants were recruited through the Prolific recruitment platform (www.prolific.co), and were naïve to the purpose of the study. All participants gave their informed consent at the start of the experiment, could withdraw from the experiment at any time, and received a fee of 90 pence for their participation. The experiment was conducted in accordance with the Declaration of Helsinki and was approved by the (EPKEB) United Ethical Review Board for Research in Psychology.

Apparatus and stimuli. The algorithm for executing the process of solving the captcha was programmed in Python (Peirce, 2007) and it behaved in a human-like manner: sometimes it speeded up or slowed down. The outputs of the algorithm were video recorded and embedded in a survey hosted on surveyMonkey.com. Participants were required to use a desktop computer to access the task.

There were eight videos in which stars progressively appeared to indicate that an agent was solving a captcha. The first level captchas consisted of 3 characters and were deciphered in 4 s in the Fast condition and in 8 s in the Slow condition. The second level captchas consisted of 6 characters and were deciphered in 7 s in the Fast condition and in 14 s

in the Slow condition. The third level captchas consisted of 10 characters and were deciphered in 8 s in the Fast condition and in 16 s in the Slow condition. The fourth level captchas consisted of 12 characters and were deciphered in 9 s in the Fast condition and in 18 s in the Slow condition. During the trials participants only saw the process of deciphering the captchas – i.e. they saw stars progressively appearing on the screen to indicate that the captcha was being solved. In order to ensure that they based their judgments on the stimulus parameters that we were manipulating, participants were not shown the captchas except for one example in the tutorial. The tutorial captcha consisted of 6 characters and were deciphered in 14 s.

Participants estimated others' effort costs of deciphering a captcha on a Likert scale (1-7), where 1 means effortless and 7 means effortful.

	Path length 3 steps	Path length 6 steps	Path length 10 steps	Path length 12 steps
Slow	***	*****	*****	*****
Fast	***	*****	*****	*****

Figure 1: Captchas. During the video, strings of asterisks appeared on the screen to indicate that an agent was solving a captcha.

Procedure. Participants were informed that they would be participating in a task in which they would have to watch recordings of people solving captchas. They were informed that they would complete 8 trials in total and that they would estimate others' effort costs of deciphering a captcha on a Likert scale (1-7), where 1 means effortless and 7 means effortful. The 8 trials were preceded by a tutorial video in which stars progressively appeared to indicate that the partner was solving a captcha and upon completion the captcha key was

revealed. At the end of the experiment, participants had to answer 3 comprehension check questions. Then participants were debriefed and paid.

Design. In a within-subject design experiment, we manipulated the process of deciphering the captcha by two factors: path length and speed/time. We manipulated Length by modifying the number of steps (characters) it takes to solve the captcha. There were four levels of captcha path length: 3, 6, 10 and 12 steps. In addition, we manipulated the Speed/Time at which these steps were taken. Captchas of the same length were completed twice as fast in the Fast condition than in the Slow condition.

To estimate the partner's effort costs in deciphering the captchas, participants used a Likert scale (1-7), where 1 means effortless and 7 means effortful.

Data preparation and analysis. We prepared and analyzed the data in rStudio (RStudio Team, 2016) using R 4.0.0 (R Core Team, 2020), the *tidyverse* (v1.3.0; Wickham et al., (2019), the *rjags* (v4-10; Martyn Plummer, 2019), the *HH* (v3.1-47; Heiberger, R. M. & Holland, B. (2015) and the *runjags* (v2.0.4-6; Matthew J. Denwood, 2016) packages.

For the Bayesian data analysis, we used a noncommittal broad prior on the parameters so that the prior had minimal influence on the posterior. We used Markov chain Monte Carlo (MCMC) techniques to generate representative credible values from the joint posterior distribution on the parameters (Kruschke, 2015). Three chains were initialized, well burned in (for 1,000 steps), and a total of 30,000 steps were saved. The chains were checked for convergence and autocorrelation and run long enough to produce an effective sample size (ESS) of at least 10,000 for all of the reported results. This yielded a stable and accurate representation of the posterior distribution on the parameters.

Results

We examined how participants rated others' effort costs in deciphering a captcha as a function of Length and Speed/Time with a two-way ordinal regression. The results revealed a significant main effect of Length ($\chi^2(3) = 353.297, p < .001$), that is, participants rated more steps (captchas consisting of more characters) as more effortful, a significant main effect of Speed/Time ($\chi^2(1) = 517.704, p < .001$), that is, participants rated actions as more effortful in the Slow condition than in the Fast condition, and also a significant interaction term ($\chi^2(3) = 18.62, p < .001$), that is, the effect of Length was greater in the Fast condition than in the Slow condition. Moreover, pairwise comparisons showed that the perceived effort costs were significantly different between each level of the factor Length (see **Figure 2**).

We examined the data with Bayesian methods as well. We used a generalized linear model, in which the predicted value is described as categorically distributed around a linear combination of nominal predictors (Speed/Time, Length, random effect of participant) mapped to a probability value via a thresholded cumulative normal function. The results revealed a main effect of Speed/Time, a main effect of Length and an interaction effect on participants' ratings. Accordingly, the credible values of the difference of Slow and Fast had a mode of -1.72 and a 95% HDI that extended from -1.83 to -1.6; zero was deemed not credible, that is, participants rated slow action as more effortful than fast action. The credible values of the difference of 3 steps and 12 steps had a mode of -1.83 and a 95% HDI that extended from -1.96 to -1.66; zero deemed not credible. Pairwise comparisons showed that perceived effort costs were different between each level of the factor Length, that is, more steps were rated as more effortful. The credible values of the interaction effect had a mode of -0.693 and a 95% HDI that extended from -0.981 to -0.382; zero deemed not credible, that is, the effect of Length was greater in the Fast condition than in the Slow condition.

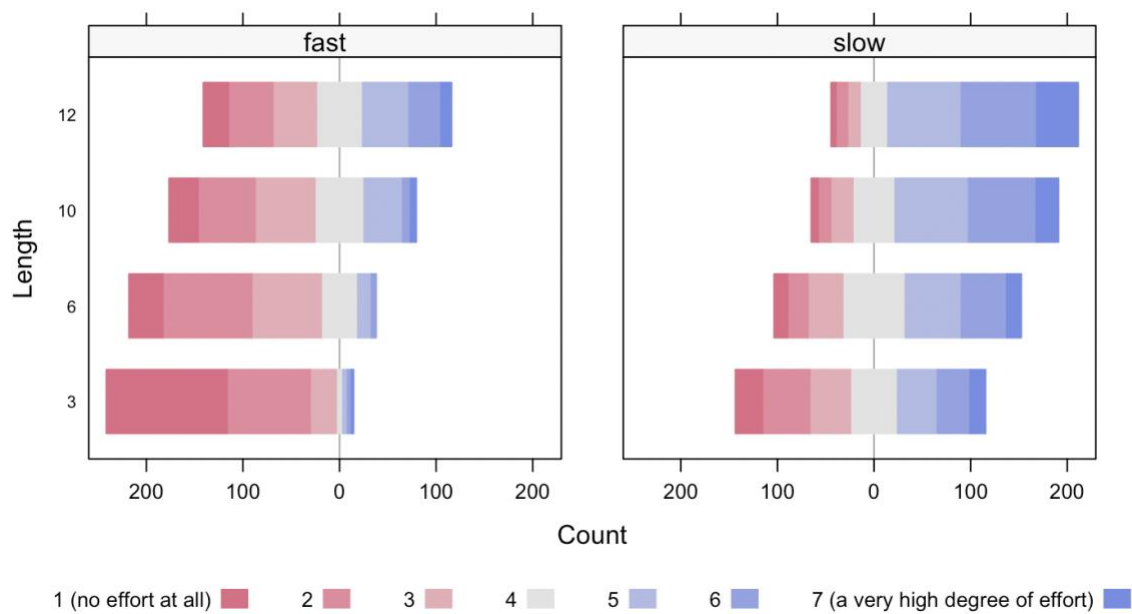


Figure 2: Participants rated others' effort costs of deciphering a captcha on a Likert scale (1-7), where 1 means “no effort at all” and 7 means “a very high degree of effort”.

Experiment 2

In Experiment 1, we found that participants rated others' effort costs in deciphering a captcha as a function of Length and Speed/Time. Specifically, they rated more steps (captchas consisting of more characters) as more effortful and they rated slow action as more effortful than fast action. Moreover, the effect of Length was greater in the Fast condition than in the Slow condition.

It is important to note that speed and time were confounded in Experiment 1. We manipulated speed by manipulating the time at which the steps were taken to solve the captcha. This means that the main effect of speed was simultaneously a main effect of time, because for each level of the factor Length, the slower action always lasted longer than the faster action. In other words, it is impossible to compare fast actions and slow actions, and in doing so to keep path length constant, without simultaneously comparing longer and shorter durations. However, if one compares *across* the levels of the factor Length, the situation is

different. To see this, consider the following. The first level captcha consisted of 3 characters and was deciphered in 8 s in the Slow condition. The third level captcha consisted of 10 characters and was deciphered in 8 s in the Fast condition. Critically, the former was rated as more effortful than the latter even though they were of the same time and the latter consisted of more steps. Thus, our results suggest that speed can have an independent effect on people's judgment on others' effort costs - regardless of the effect of time or path length.

However, the conjecture that speed has an independent effect on people's judgment on others' effort costs has not yet been directly tested or confirmed – it is merely supported by an exploratory comparison of two conditions. To further investigate the separate effects of speed and time on participants' judgment on others' effort costs, we ran a second experiment. In doing so, we manipulated Time by modifying the number of seconds it takes to solve the captcha (8.7 s, 13.51 s, 17.48 s) and we manipulated Speed/Length: each level of Time was completed with two path lengths, i.e., twice as many steps had to be taken in the Fast condition as in the Slow condition. We predicted a main effect of Time and a main effect of Speed/Length.

Method

Participants. Our target sample was 200 participants as in Experiment 1. We collected data from 208 participants. Of these, 5 individuals were excluded from analyses because they did not complete the task or failed 2 of 3 comprehension check questions, leaving a sample of 203 (i.e. 203 participants: 80 female, $M_{\text{age}} = 28.03$ years, $SD_{\text{age}} = 10.11$ years) participants in the final dataset. All participants were recruited through the Prolific recruitment platform (www.prolific.co), and were naïve to the purpose of the study. All participants gave their informed consent at the start of the experiment, could withdraw from the experiment at any time, and received a fee of 80 pence for their participation. The experiment was conducted in

accordance with the Declaration of Helsinki and was approved by the (EPKEB) United Ethical Review Board for Research in Psychology.

Apparatus and stimuli. The apparatus and stimuli were identical to that of Experiment 1 except for the following.

There were six videos in which stars progressively appeared to indicate that an agent was solving a captcha. The first level captchas were deciphered in 8.7 s and consisted of 3 characters in the Slow condition and 6 characters in the Fast condition. The second level captchas were deciphered in 13.51 s and consisted of 6 characters in the Slow condition and 12 characters in the Fast condition. The third level captchas were deciphered in 17.48 s and consisted of 12 characters in the Slow condition and 24 characters in the Fast condition.

Procedure. The procedure was identical to that of Experiment 1.

Design. In a within-subject design experiment, we manipulated the process of deciphering the captcha by two factors: Time and Speed/Length. We manipulated Time by modifying the number of seconds it takes to solve the captcha. There were three levels of Time: 8.7, 13.51, 17.48 s. In addition, we manipulated Speed/Length: each level of Time was completed with two path lengths, that is, twice as many steps had to be taken in the Fast condition than in the Slow condition. The dependent measure was identical to that of Experiment 1.

Data preparation and analysis. The data preparation and analysis were identical to that of Experiment 1.

Results

We examined how participants rated others' effort costs in deciphering a captcha as a function of Time and Speed/Length with a two-way ordinal regression. The results revealed a significant main effect of Time ($\chi^2(2) = 232.581, p < .001$), that is, longer time was rated as

more effortful, no main effect of Speed/Length ($\chi^2 (1) = 1.784, p=.181$), and a significant interaction term ($\chi^2 (2) = 34.802, p<.001$). Specifically, we found three different effects of Speed/Path length depending on the level of Time, i.e., participants rated fast action as more effortful than slow action when the duration was 8.7 s, participants rated fast action and slow action similarly when the duration was 13.51 s and participants rated slow action as more effortful than fast action when the duration was 17.48 s. Moreover, pairwise comparisons showed that perceived effort costs were significantly different between each level of the factor Time (see **Figure 3**).

We examined the data with Bayesian methods as well. We used a generalized linear model, in which the predicted value is described as categorical distributed around a linear combination of nominal predictors (Speed/Length, Time, random effect of participant) mapped to a probability value via a thresholded cumulative normal function. The results revealed no main effect of Speed/Length, a main effect of Time and an interaction effect on participants' ratings. Accordingly, the credible values of the difference of Slow and Fast had a mode of 0.0863 and a 95% HDI that extended from -0.066 to 0.22; zero was deemed credible. The credible values of the difference of 8.7 s and 17.48 s had a mode of -0.624 and a 95% HDI that extended from -0.842 to -0.474; zero deemed not credible. Pairwise comparisons showed that perceived effort costs were different between each level of Time, that is, longer time was rated as more effortful. The credible values of the interaction effect had a mode of 1.28 and a 95% HDI that extended from 0.92 to 1.66; zero deemed not credible.

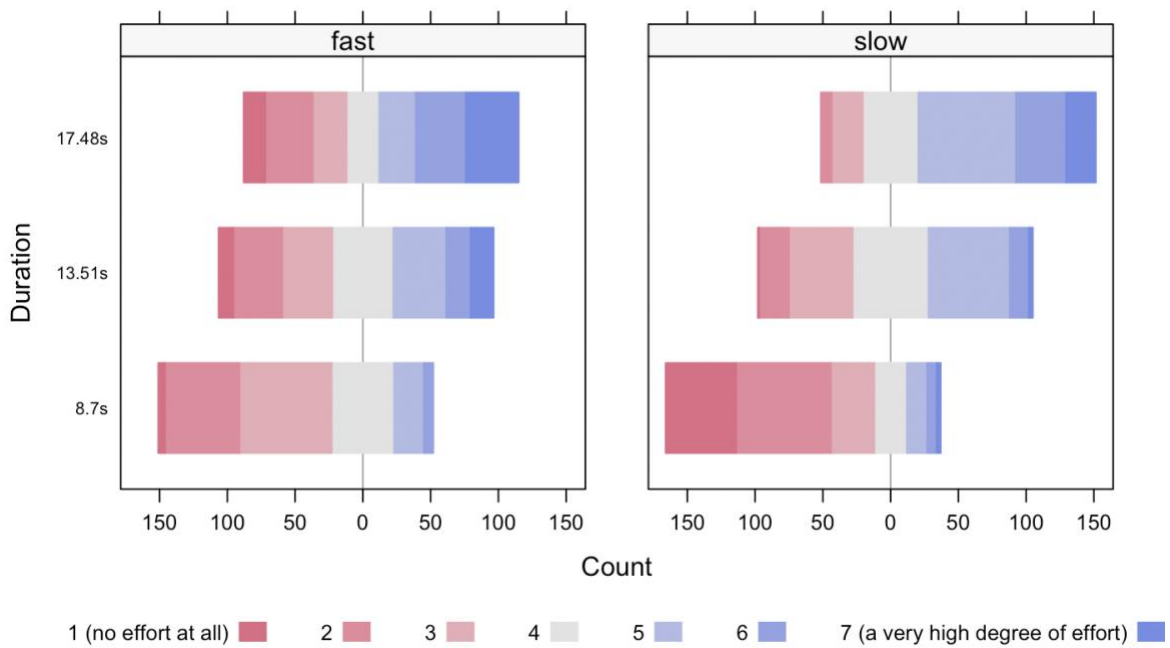


Figure 3: Participants rated others' effort costs of deciphering a captcha on a Likert scale (1-7), where 1 means “no effort at all” and 7 means “a very high degree of effort”.

General Discussion

Effort perception is a crucial capacity underpinning characteristically human forms of sociality, allowing us to learn about others' mental states and about the value of opportunities afforded by our environment, and supporting our ability to cooperate efficiently and fairly. Across two experiments, we provide new insight into how people estimate the effort costs that observed agents are investing in specific ongoing activities. In Experiment 1, we found that participants rated others' effort costs in deciphering a captcha as a function of Length and Speed/Time. Specifically, they rated more steps (captchas consisting of more characters) as more effortful, and for each level of the factor Length they rated slow action as more effortful than fast action. Moreover, the effect of Length was greater in the Fast condition than in the Slow condition. Importantly, in Experiment 1, we could not cleanly separate the effect of speed and time because, within each level of the factor Length, the slower action always lasted longer than the faster action – in other words, the main effect of Speed was also a main

effect of Time. However, when looking across levels of the factor Length, we were able to compare faster and slower actions with the same duration (i.e. with different path lengths). This analysis revealed that slower actions were perceived as more effortful than faster actions even when the time was constant. Building on this finding in Experiment 2, we manipulated Time and Speed/Length independently. We found a main effect of Time, that is, longer time was rated as more effortful, no main effect of Speed/Length and an interaction effect. Specifically, we found three different effects of Speed/Length depending on the level of Time, i.e., at the level of the shortest time, fast action was rated more effortful than slow action; at the middle level time, fast action was rated similarly to slow action; and at the level of the longest time, fast action was rated as less effortful than slow action. Critically, in Experiment 2, we could not separate the effect of Speed and Length because, for each level of the factor Time, the faster action always consisted of more steps than the slower action. This means that Length did not have a main effect on effort perception either. This is in contrast to the results of Experiment 1, where we found a main effect of Length. Across the two experiments, only Time had a consistent effect on effort perception, i.e., participants rated longer time as more effortful. Taken together, our results suggest that within the context of our task - observing an agent deciphering a captcha - people rely on the time of others' action to estimate others' effort costs.

Why did participants interpret longer time as an indication of higher level of effort? One possibility is that the way people process movement cues with respect to estimating others' effort costs depends on the task and other contextual cues. For example, in our task participants saw stars progressively and continuously appearing on the screen that might have been interpreted as a sign of engaged attention and therefore the continuous investment of cognitive effort. However, our stimuli could be modified so that time would not necessarily correspond to attentional engagement. For example, the stars could begin appearing on the

screen and then stop, followed by a long pause after which stars continue appearing and the captcha is completed - signalling attentional disengagement and the cessation of cognitive effort in the middle of the action. In this case, participants may not interpret the longer time as a sign of a higher level of effort. Alternatively, it may be that people have a general expectation that greater magnitude in time covaries with greater outlays of energy – regardless of contextual cues. If so, we should expect to find this effect of time across a wide range of tasks. Thus, future research should investigate whether people differentiate between different kinds of time: time of engaged and disengaged attention, or more generally whether people’s perception of others’ effort costs through movement cues depends on contextual factors.

The current findings contribute to previous research in several ways. First, they provide a crucial test of assumptions about effort perception made by a large body of work using movement cues as a basis for effort perception. To our knowledge, the experiments reported here are the first to directly test how adults perceive others’ effort costs. In addition, our results suggest that adults perceive *cognitive effort* through movement cues. The difference in perceiving cognitive or physical effort is important because cognitive and physical effort differ characteristically in their appearance to an observer. For example, when an agent does not exert a high degree of physical force, it is appropriate to judge them to be exerting a low level of physical effort or no physical effort at all – however, they may be still exerting a high level of cognitive effort, such as inhibiting impulses, maintaining a task set or engaging in mental planning. Accordingly, our findings suggest that participants appraised slowness as indicative of high cognitive effort regardless of time, although this was not a consistent effect. Further research is needed to investigate the differences in how we perceive cognitive and physical effort.

Our findings also complement existing research on how people compare the relative difficulty of different kinds of tasks. For example, Gray, Sims, Fu, and Schoelles (2006) found that participants chose between perceptual-motor strategies and cognitive strategies as a function of time to minimize time on task. Building on these results, Potts, Pastel & Rosenbaum (2018) and Rosenbaum & Bui (2019) invited participants to choose between a counting task and a bucket carrying task. They found that relative task duration predicted participants' choices. Taken together, time spent on a task appears to be a general proxy to estimate effort costs.

The present study raises key questions for future research. For example: What is the functional form of the relationship between time and the perception of others' effort costs? A linear model predicts a constant effect of duration on effort perception regardless of the absolute value of duration. But there are other possibilities. For instance, a hyperbolic model predicts that changes in short duration have a stronger impact than changes in long duration. In contrast, a parabolic model predicts the opposite: changes in long duration have a stronger impact than changes in short duration. In sum, these three functions differ in their assumptions on how increasing duration impacts effort perception. Identifying the relevant functional form is important insofar as it would enable us to design more precise stimuli for various research programs that build on our ability to perceive others' effort. Future research should address this question by developing theories that make precise predictions about the form of this function, and empirically distinguishing among them.

Moreover, in our study, we focused on the systematic differences in how people rate others' effort costs in deciphering a captcha. However, our study did not speak to the accuracy of these ratings. An interesting next step would be to test this by correlating participants' ratings of others' effort costs with those other agents' own internal assessment of their effort investment.

Finally, the cognitive and neural architecture underlying our ability to perceive others' effort remains to be explored. Our findings suggest that we perceive others' effort costs by tracking perceptible properties of movements. To investigate the neural basis of this ability, future work could draw upon existing findings from neurophysiological research on how people track others' motivation (Apps, Rushworth, & Cheng, 2016). In addition, building on results suggesting that during observation of an action, a corresponding representation in the observer's cortical motor system is activated (Rizzolatti and Craighero, 2004; Frith & Singer, 2008), it may be fruitful to explore the possibility that we perceive others' effort through our own motor system. Or one may speculate that we estimate effort costs by tracking perceptible properties of others' autonomic nervous systems such as breathing patterns and cues of muscle tension because cues to the level of activity of the autonomic nervous system convey information about the current level of effort investment (Rejeski & Lowe, 1980; de Morree & Marcora, 2010). Further research is needed to distinguish among these hypotheses and to clarify how we integrate these various sources of information.

Open practices

The experiments were pre-registered prior to data collection [Experiment 1: https://aspredicted.org/66S_SNW ; Experiment 2: https://aspredicted.org/7WD_F6D]. The reproducible scientific reports (data and analysis code) are available in an online repository here: [https://osf.io/rca7b/?view_only=087a03a5f7f741ffb346a89de3ed93c7].

Chapter 3. Effort-Based Decision Making in Joint Action: Evidence of a Sense of Fairness

As humans, we have unique skills and motivations for acting together (Tomasello et al., 2012; Sebanz, Bekkering & Knoblich, 2006; Nowak, 2006). Crucially, acting together requires effort - and recent empirical research on joint action has begun focusing on how people negotiate economies of effort. In one line of research (Székely & Michael, 2018; Chennells & Michael, 2018), it has been found that people make use of perceptual cues to infer a partner's investment of effort and aim to calibrate their effort level to match that of their partner's effort costs - however, these studies do not resolve the question as to why, or under what circumstances, people do so.

Research on the evolution of cooperation provides a tentative explanation. In particular, recent research on strategies for cooperation in biological markets suggests that when individuals can choose partners, this can lead to selection pressure favoring psychological adaptations for choosing, attracting and maintaining good collaboration partners (Barclay, 2013; Barclay & Willer, 2007). Building on this, one may speculate that people calibrate their effort investment in joint action with the ultimate goal of attracting and keeping good collaboration partners (*The relationship-directed effort calibration hypothesis*).

If it is true that people tend to calibrate their effort investment in joint action with this ultimate goal, what proximal psychological motives drive them to do so? One possibility is linked to fairness. A growing body of theoretical and empirical work suggests that our sense of fairness implies a preference for divisions of rewards that are proportional to contributions (André and Baumard, 2011; Baumard, André & Sperber, 2013; Debove, Baumard and André, 2017; Frohlich, Oppenheimer and Kurki, 2004; Hamann, Bender and Tomasello, 2014; Kanngiesser and Warneken, 2012). This research has established that people are highly sensitive to the distribution of effort costs, and that reward distribution is governed by a sense of fairness which takes effort investments into account. Extending these results, Székely &

Michael (in press) recently provided evidence that the sense of fairness leads people to distribute effort costs according to the expected reward distribution. This ability is important because in many contexts the success of joint action is uncertain and/or the outcome is indivisible. For example, hunting and foraging in ancestral environments were uncertain endeavors, and may not have yielded any outcome to distribute. In such instances, the only way to exhibit a sense of fairness is to invest effort equally. This line of reasoning leads us to the following hypothesis: when people expect to share the reward of the joint task equally, we should expect them to ensure fairness by calibrating their effort investment such as to reduce inequity with respect to joint action partners' effort investment (*The equity through effort calibration hypothesis*).

The current study was designed to test the hypothesis that people calibrate their effort investment in joint action with the ultimate goal of attracting and keeping good collaboration partners and that the proximal psychological motive that drives them to do so is a preference for fairness. In doing so, it is crucially important to distinguish an alternative explanation arising from the fact that sometimes the value of opportunities afforded by the environment is uncertain. In such circumstances, one may use others' investment of effort to infer the reward value they anticipate from an action. For example, if the partner is pursuing a high-cost plan of action, one can infer that the partner expects a high reward. Accordingly, people may use their partner's effort costs as information to infer the value of opportunities afforded by their environment, which may lead them to adjust their effort investment as a function of the inferred value (*The environment-directed effort calibration hypothesis*).

To distinguish between these hypotheses, we implemented a social effort lottery task with an unknown reward. In Experiment 1, the rewards were sometimes the same (Congruent) and sometimes the opposite (Incongruent) for the participant and the partner; we also manipulated the partner's effort level (High and Low). We reasoned that if participants

use the perception of their partner's effort investment as an input to infer the reward value of a trial, then we should expect participants to invest more effort in the High Partner Effort condition than in the Low Partner Effort condition, while in the Incongruent condition, they should invest more effort in the Low Partner Effort condition than in the High Partner Effort condition. In contrast, if participants use the perception of their partner's effort investment to ensure fairness by calibrating their effort investment such as to reduce inequity with respect to joint action partners' effort investment, then we should expect participants to invest more effort in the High Partner Effort condition than in the Low Partner Effort condition regardless of Congruence.

The second and third experiments were designed to rule out an alternative explanation which may equally explain effort calibration in joint action with the ultimate goal of attracting and keeping good collaboration partners. People may be motivated to appear competent and efficient as a means of increasing their value as collaborative partners. Therefore, people may calibrate their effort investment to their partner's belief about the potential reward value of their action (*The appearance of being competent hypothesis*).

In Experiment 2, we again manipulated 1) participants' beliefs about the reward structure of the task (Congruent and Incongruent), and 2) partner's effort (High and Low). But in Experiment 2, unlike Experiment 1, participants were informed that their partner always believed that they were in the Congruent reward structure. This made it possible to rule out an alternative explanation for Experiment 1, namely that different subsets of participants may have drawn different inferences about whether their partner was aware that the reward structures were opposite in the Incongruent condition, and accordingly have felt the need either to match their partner's effort level or to do the opposite to appear as competent collaboration partners (*The appearance of being competent hypothesis*).

In Experiment 3, we again manipulated 1) partner's effort (High and Low). Moreover, instead of manipulating the Congruence of reward structure, participants were tested in an uncertain reward structure – that is, participants did not know whether they were in a Congruent or Incongruent condition. In addition, in Experiment 3 participants were informed that their partner always believed that they were in an incongruent reward structure. This design enabled us to distinguish the equity through effort calibration hypothesis from the appearance of being competent hypothesis while ensuring that the environment-directed calibration would not play a role in their decision-making. While the equity through effort calibration hypothesis predicts that participants should match their partner's effort more in the High Partner Effort condition than in the Low Partner Effort condition in order to appear as fair collaboration partners, the appearance of being competent hypothesis generates the opposite prediction.

Experiment 1

Method

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study.

Participants. Using G*power (Faul, Erdfelder, Buchner, & Lang, 2009), we determined that a sample size of 40 participants provides 80% power to detect an effect size of $f=0.1876$ or greater in a repeated measures ANOVA with a 5% false-positive rate. During the data collection process, we excluded one pair whose members knew each other prior to participation. The sample includes twenty pairs of individuals (29 female, $M_{\text{age}} = 24.37$ years, $SD_{\text{age}} = 3.32$ years). We did not exclude any data point from the analysis. Participants carried out the experiment in pairs; members in each pair did not know each other prior to participation. Participants were recruited through Central European University's Research

Participation System (developed by SONA Systems; <https://www.sona-systems.com/default.aspx>) and through a student organization (Márton Áron Diákszövetkezet) in the Budapest area, were naïve to the purpose of the study, and reported normal or corrected to normal vision. All participants gave their informed written consent prior to the experiment and received gift vouchers for their participation. The experiment was conducted in accordance with the Declaration of Helsinki and was approved by the (EPKEB) United Ethical Review Board for Research in Psychology.

Apparatus and stimuli. The experiment was displayed on a 13-inch computer screen (resolution: 2560×1600 pixels, refresh rate: 60 Hz). The program for the experiment was written in Python (Peirce, 2007).

Procedure. Participants were first introduced to another participant in the waiting area, whom they were told would be their partner for the experiment, and who would be playing in the adjacent room (in fact, both of them were playing with a virtual partner controlled by the computer, so that maximum experimental control could be maintained). They were informed that their task was to collect points together with their partner and each point increased the probability of getting a bonus at the end of the experiment. Crucially, they were informed that the bonus would be evenly divided between them.

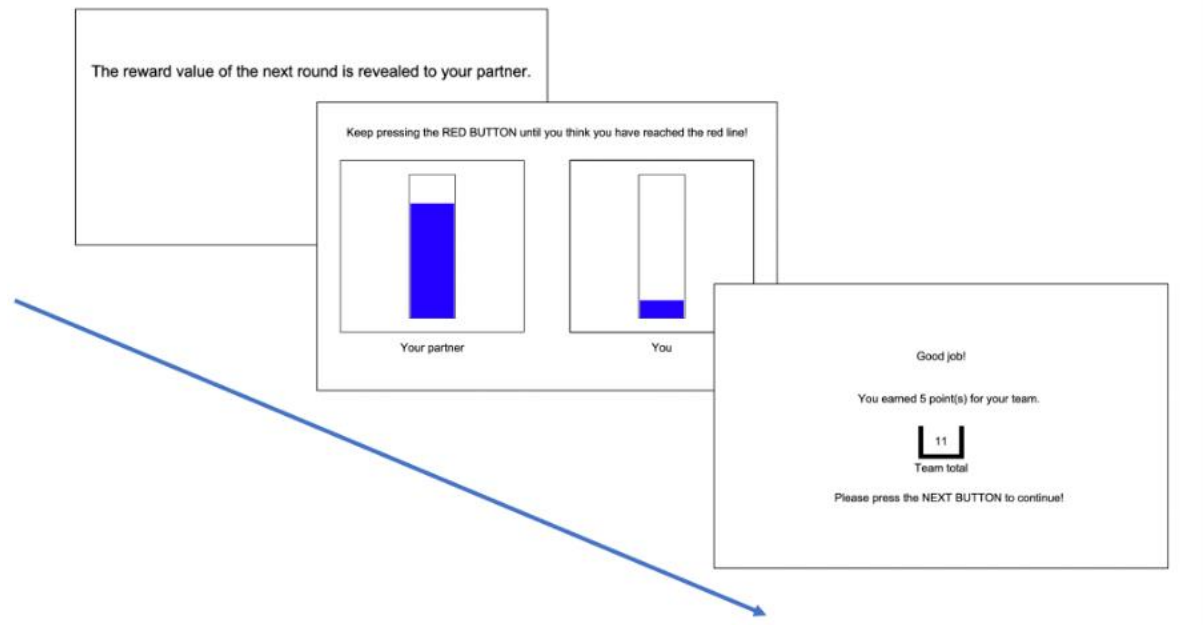


Figure 1: Trial structure. On each trial, participants observed their (virtual) partner performing the effort lottery task before their own turn on the same task for some reward value.

On the effort lottery task, participants had to repeatedly press a button to reach a target in order to obtain an unknown reward (1 or 5 points). When they reached or surpassed the target, they received points. Critically, the target was invisible, so participants could not know whether or not they had reached it when deciding how long to persist before quitting. On quitting, participants received feedback about how many points they earned, but they never learned about the location of the invisible target. Before their turn, they observed as their partner performed the same task in order to obtain some reward (1 or 5 points). Importantly, at the beginning of each trial, the reward value of the trial was only revealed to their partners and their partners invested effort rationally: when they (i.e., partners) had high reward (5 points), they invested a high level of effort (High Partner Effort condition); when they had low reward (1 point), then they invested a low level of effort (Low Partner Effort condition) (see **Figure 1**).

The experiment was preceded by four tutorials. The first tutorial introduced participants to the effort lottery task with visible targets; they learned that they had to repeatedly press a button to reach the target and then they had to quit the effort lottery task by pressing another button. The second tutorial introduced participants to the effort lottery task with invisible targets: they had to decide when to quit without knowing whether they had reached the target. The partner's component was introduced in the third tutorial; in four trials, the partner invested 60, 25, 30 and 85 keypresses before quitting.

Design. In a within-subject design experiment, we manipulated participants' beliefs about the reward structure of the task: in one block, they were led to correctly believe that when their partner had high reward for a trial, then they had high reward too, and when their partner had low reward for a trial, then they had low reward as well (Congruent condition); while in another block, they were led to correctly believe that when their partner had high reward for a trial, then they had low reward, and when their partner had low reward for a trial, then they had high reward (Incongruent condition). Furthermore, sometimes their partners invested a high level of effort (High Partner Effort condition), and sometimes they invested a low level of effort (Low Partner Effort condition). In each condition, there were 5 trials and we measured participants' number of keypresses before quitting.

Data preparation and analysis. We prepared and analyzed the data in rStudio (RStudio Team, 2016) using R 4.0.0 (R Core Team, 2020), the tidyverse (v1.3.0; Wickham et al., (2019), the rjags (v4-10; Martyn Plummer, 2019) and the runjags (v2.0.4-6; Matthew J. Denwood, 2016) packages.

For the Bayesian data analyses, we decided to use parameter estimation instead of model comparison because parameter estimation provides an explicit posterior distribution on the parameters, and so it provides more meaningful information than model comparison

(Kruschke, 2015). We used a noncommittal broad prior on the parameters so that the prior had minimal influence on the posterior. We used Markov chain Monte Carlo (MCMC) techniques to generate representative credible values from the joint posterior distribution on the parameters. Three chains were initialized, well burned in (for 1,000 steps), and a total of 30,000 steps were saved. The chains were checked for convergence and autocorrelation and run long enough to produce an effective sample size (ESS) of at least 10,000 for all of the reported results. This yielded a stable and accurate representation of the posterior distribution on the parameters. See the reproducible scientific report for details.

Results

To examine the effect of Partner's Effort and Congruence on participants' effort investment in the form of keypresses, we planned to perform a repeated measures ANOVA and a Bayesian analysis, and pre-registered them as the planned analyses. Prior to conducting this analysis, we performed a Shapiro-Wilk test on all four conditions and three of them showed evidence of non-normality (High Congruent ($M=280$, $Mdn=272$, $SD=99.8$), $W=0.908$, $p=0.00323$; Low Congruent ($M=159$, $Mdn=150$, $SD=85.9$), $W=0.896$, $p=0.00147$; High Incongruent ($M=232$, $Mdn=234$, $SD=108$), $W=0.952$, $p=0.0886$); Low Incongruent ($M=229$, $Mdn=223$, $SD=116$), $W=0.931$, $p=0.0170$) (see **Figure 2**). Because the assumption of normality was not met, we could not perform a repeated measures ANOVA as we had pre-registered. We analyzed the data with Bayesian methods with the pre-registered model. We used a generalized linear mixed model, in which the predicted value is described as negative binomial distributed around a linear combination of categorical predictors (Partner's Effort, Congruence, random effect of participant and random slopes of condition nested within participant) mapped to the central tendency of the predicted value via the exponential function. The results revealed a main effect of Partner Effort, no main effect of Congruence, and an interaction. Accordingly, the credible values of the difference of Partner Effort had a

mode of 0.329 and a 95% HDI that extended from 0.275 to 0.389; zero deemed not credible. The credible values of the difference of Congruence of Reward Structure had a mode of -0.057 and a 95% HDI that extended from -0.114 to 0.000243; zero deemed credible. The credible values of the difference of differences had a mode of 0.63 and a 95% HDI that extended from 0.514 to 0.743; zero deemed not credible. Moreover, the results revealed a simple effect of Partner Effort in the Congruent condition, that is, participants invested more effort in the High Partner Effort condition than in the Low Partner Effort condition, and no simple effect of Partner Effort in the Incongruent condition. Accordingly, the credible values of the difference of High Congruent and Low Congruent had a mode of 0.634 and a 95% HDI that extended from 0.573 to 0.727; zero was not deemed credible. The credible values of the difference of High Incongruent and Low Incongruent had a mode of 0.0161 and a 95% HDI that extended from -0.077 to 0.0863; zero was deemed credible. The results also revealed a simple effect of Congruence in the High Partner Effort condition, that is, participants invested more effort in the Congruent condition than in the Incongruent condition, and a simple effect of Congruence in the Low Partner Effort condition, that is, participants invested more effort in the Incongruent condition than in the Congruent condition. Accordingly, the credible values of the difference of High Congruent and High Incongruent had a mode of 0.254 and a 95% HDI that extended from 0.177 to 0.341; zero was deemed not credible. The credible values of the difference of Low Congruent and Low Incongruent had a mode of -0.367 and a 95% HDI that extended from -0.443 to -0.239; zero was deemed not credible.

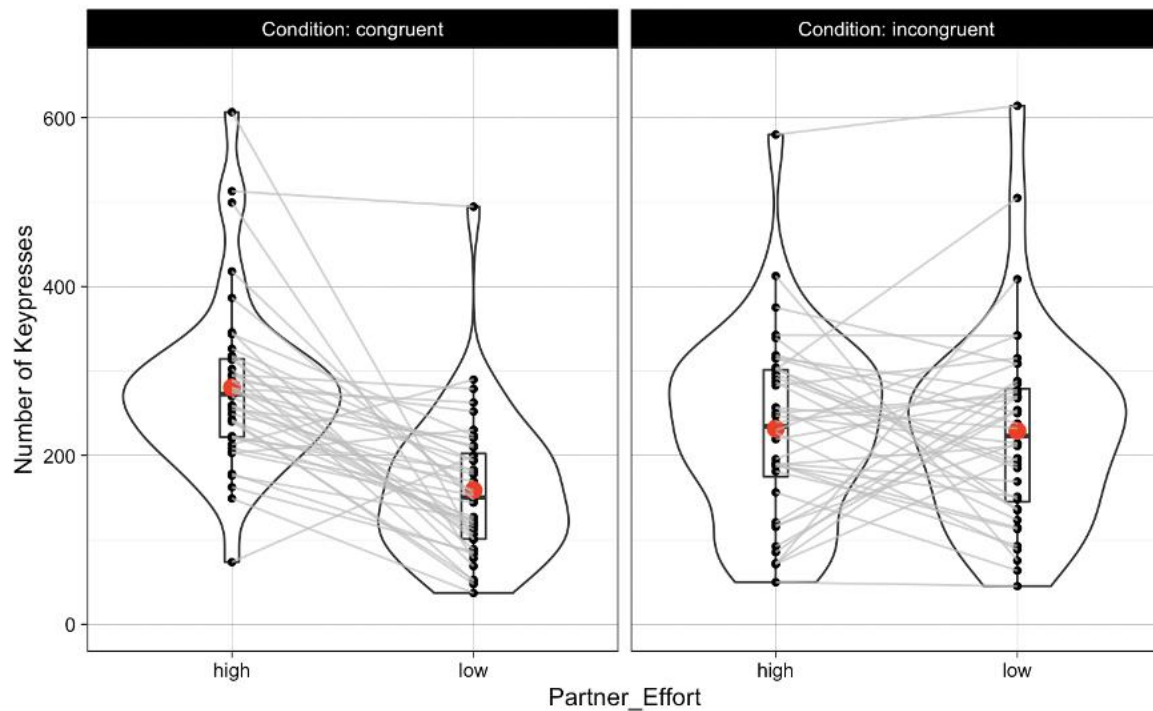


Figure 2: Participants’ effort investment in the form of keypresses across conditions. Each black dot represents one participant’s effort investment in the respective condition and the gray line connects one’s effort investment in the High and Low Partner’s Effort conditions within the respective Congruence condition. In each boxplot, horizontal lines indicate medians, and red circles indicate means.

Although in the Incongruent condition we did not find any difference between the High and Low Partner’s Effort conditions at the group level, participants’ effort investments in the Incongruent condition suggested that there is a difference at the individual level. Specifically, there appears to be a subset of participants who invested more effort in the Low Partner Effort condition than in the High Partner Effort condition (Environment-directed effort calibration group), while there appears to be a distinct subset of participants who invested more effort in the High Partner Effort condition than in the Low Partner Effort condition (Relationship-directed effort calibration group) (see **Figure 3**). To probe this, as an exploratory analysis, we analyzed the data of both subsets of participants separately by applying the same pre-registered Bayesian model. The results of the Environment-directed

effort calibration group revealed a main effect of Partner Effort, a main effect of Congruence, and an interaction. Accordingly, the credible values of the difference of Partner Effort had a mode of 0.0773 and a 95% HDI that extended from 0.0105 to 0.157; zero was deemed not credible. The credible values of the difference of Congruence of Reward Structure had a mode of -0.118 and a 95% HDI that extended from -0.188 to -0.0347; zero was deemed not credible. The credible values of the difference of differences had a mode of 1.39 and a 95% HDI that extended from 1.26 to 1.56; zero was deemed not credible. Moreover, the results revealed a simple effect of Partner Effort in the Congruent condition, that is, participants invested more effort in the High Partner Effort condition than in the Low Partner Effort condition, and a simple effect of Partner Effort in the Incongruent condition, that is, participants invested more effort in the Low Partner Effort condition than in the High Partner Effort condition. Accordingly, the credible values of the difference of High Congruent and Low Congruent had a mode of 0.796 and a 95% HDI that extended from 0.68 to 0.9; zero was not deemed credible. The credible values of the difference of High Incongruent and Low Incongruent had a mode of -0.628 and a 95% HDI that extended from -0.726 to -0.52; zero was deemed credible. The results also revealed a simple effect of Congruence in the High Partner Effort condition, that is, participants invested more effort in the Congruent condition than in the Incongruent condition, and a simple effect of Congruence in the Low Partner Effort condition, that is, participants invested more effort in the Incongruent condition than in the Congruent condition. Accordingly, the credible values of the difference of High Congruent and High Incongruent had a mode of 0.573 and a 95% HDI that extended from 0.489 to 0.703; zero was deemed not credible. The credible values of the difference of Low Congruent and Low Incongruent had a mode of -0.809 and a 95% HDI that extended from -0.933 to -0.718; zero was deemed not credible.

The results of the Relationship-directed effort calibration group revealed a main effect of Partner Effort, no main effect of Congruence, and no interaction. Accordingly, the credible values of the difference of Partner Effort had a mode of 0.503 and a 95% HDI that extended from 0.427 to 0.592; zero was deemed not credible. The credible values of the difference of Congruence of Reward Structure had a mode of 0.00514 and a 95% HDI that extended from -0.0978 to 0.0648; zero was deemed credible. The credible values of the difference of differences had a mode of 0.065 and a 95% HDI that extended from -0.101 to 0.23; zero was deemed not credible.

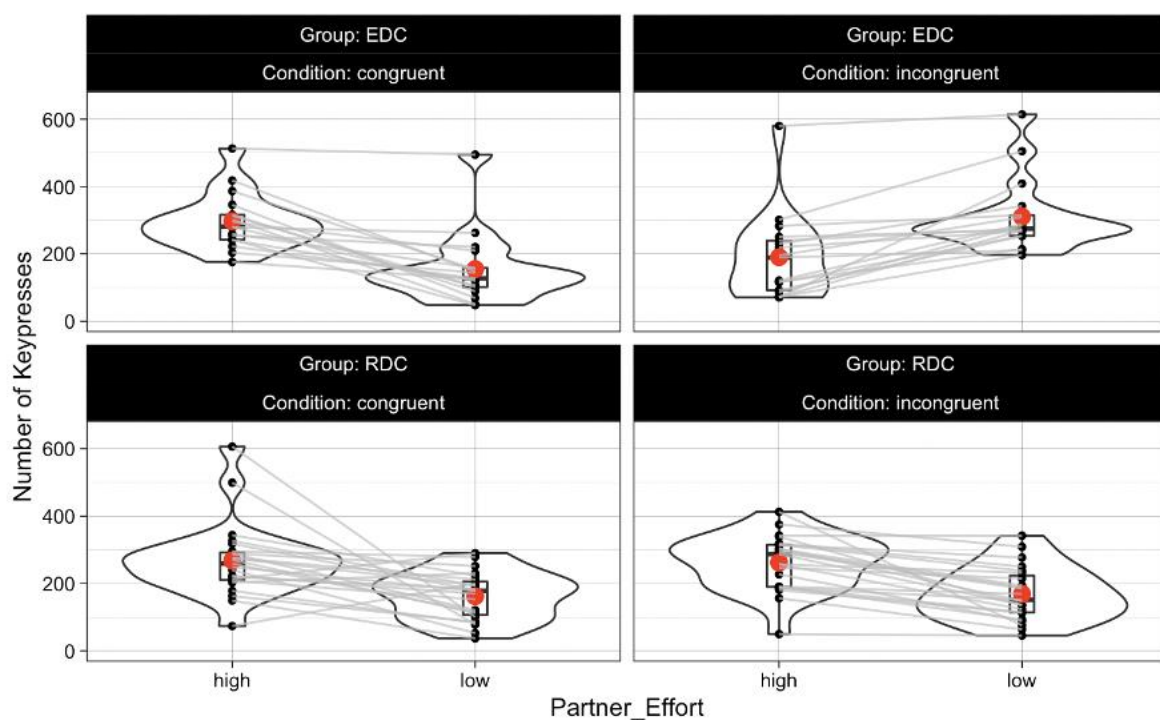


Figure 3: Participants' effort investment in the form of keypresses across conditions, split into two groups. The environment-directed effort calibration group (EDC) exhibits a change from effort matching to inverse effort matching when the reward structure is incongruent rather than congruent. The relationship-directed effort calibration group (RDC) exhibits no such change. Each black dot represents one participant's effort investment in the respective condition, and the gray line connects each participant's effort investment in the High and

Low Partner's Effort conditions within the respective Congruence of reward structure condition. In each boxplot, horizontal lines indicate medians, and red circles indicate means.

Experiment 2

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study.

Method

Participants. Using G*power (Faul, Erdfelder, Buchner, & Lang, 2009), we determined that a sample size of 40 participants provides 80% power to detect an effect size of $f=0.1876$ or greater in a repeated measures ANOVA with a 5% false-positive rate. We followed the pre-registered exclusion criteria: accordingly, we excluded 20 participants who failed the belief manipulation check at the end of the experiment (2 participants said that „My partner thought that the available reward value was always the opposite for them and for me.”; 15 participants said that „My partner thought that the available reward value was in one block the same, in another block the opposite for them and for me. ”; 3 participants said that „I don't remember what my partner thought about the available reward value.”) and we excluded 2 participants who were accidentally disturbed during the experiment by another participant. The sample includes forty individuals (25 female, $M_{age} = 26.45$ years, $SD_{age} = 7.11$ years). We did not exclude any data point from the analysis. Participants carried out the experiment in pairs; members in each pair did not know each other prior to participation. Participants were recruited through Central European University's Research Participation System (developed by SONA Systems; <https://www.sona-systems.com/default.aspx>) in the Vienna area, were naïve to the purpose of the study, and reported normal or corrected to normal vision. All participants gave their informed written consent prior to the experiment and received gift vouchers for their participation. The experiment was conducted in accordance with the

Declaration of Helsinki and was approved by the (PREBO) Psychological Research Ethics Board.

Apparatus and stimuli. The apparatus and stimuli were identical to that of Experiment 1.

Procedure. The procedure was identical to that of Experiment 1 except that at the end of the experiment, participants had to answer belief manipulation check questions regarding their partner's belief about the congruence of reward structure.

Design. The design was identical to that of Experiment 1 except that participants believed that their (virtual) partner always believed that they were in a congruent reward structure. The dependent measure was identical to that of Experiment 1.

Data preparation and analysis. We prepared and analyzed the data in rStudio (RStudio Team, 2016) using R 4.0.0 (R Core Team, 2020), the tidyverse (v1.3.0; Wickham et al., (2019), the rjags (v4-10; Martyn Plummer, 2019) and the runjags (v2.0.4-6; Matthew J. Denwood, 2016) packages.

For the Bayesian data analyses, we decided to use parameter estimation instead of model comparison because parameter estimation provides an explicit posterior distribution on the parameters and so it provides more meaningful information than model comparison (Kruschke, 2015). We used a noncommittal broad prior on the parameters so that the prior had minimal influence on the posterior. We used Markov chain Monte Carlo (MCMC) techniques to generate representative credible values from the joint posterior distribution on the parameters. Three chains were initialized, well burned in (for 1,000 steps), and a total of 30,000 steps were saved. The chains were checked for convergence and autocorrelation and run long enough to produce an effective sample size (ESS) of at least 10,000 for all of the

reported results. This yielded a stable and accurate representation of the posterior distribution on the parameters. See the reproducible scientific report for details.

Results

To examine the effect of Partner's Effort and Congruence on participants' effort investment in the form of keypresses, we planned to perform a repeated measures ANOVA and a Bayesian analysis, and pre-registered them as the planned analyses. Prior to conducting this analysis, we performed a Shapiro-Wilk test on all four conditions and two of them showed evidence of non-normality (High Congruent ($M=309$, $Mdn=287$, $SD=101$), $W=0.858$, $p=0.000139$; Low Congruent ($M=167$, $Mdn=158$, $SD=76.8$), $W=0.961$, $p=0.184$; High Incongruent ($M=241$, $Mdn=242$, $SD=96.1$), $W=0.921$, $p=0.00836$; Low Incongruent ($M=243$, $Mdn=240$, $SD=82.2$), $W=0.972$, $p=0.429$) (see **Figure 4**). Because the assumption of normality was not met, we could not perform a repeated measures ANOVA as we had pre-registered. We analyzed the data with Bayesian methods with the pre-registered model. We used a generalized linear mixed model, in which the predicted value is described as negative binomial distributed around a linear combination of categorical predictors (Partner's Effort, Congruence, random effect of participant and random slopes of condition nested within participant) mapped to the central tendency of the predicted value via the exponential function. The results revealed a main effect of Partner Effort, a main effect of Congruence, and an interaction. Accordingly, the credible values of the difference of Partner Effort had a mode of 0.33 and a 95% HDI that extended from 0.29 to 0.386; zero deemed not credible. The credible values of the difference of Congruence of Reward Structure had a mode of -0.0746 and a 95% HDI that extended from -0.122 to -0.0241; zero deemed not credible. The credible values of the difference of differences had a mode of 0.692 and a 95% HDI that extended from 0.599 to 0.802; zero deemed not credible. Moreover, the results revealed a simple effect of Partner Effort in the Congruent condition, that is, participants invested more

effort in the High Partner Effort condition than in the Low Partner Effort condition, and no simple effect of Partner Effort in the Incongruent condition. Accordingly, the credible values of the difference of High Congruent and Low Congruent had a mode of 0.675 and a 95% HDI that extended from 0.609 to 0.751; zero was not deemed credible. The credible values of the difference of High Incongruent and Low Incongruent had a mode of -0.00304 and a 95% HDI that extended from -0.09 to 0.0523; zero was deemed credible. The results also revealed a simple effect of Congruence in the High Partner Effort condition, that is, participants invested more effort in the Congruent condition than in the Incongruent condition, and a simple effect of Congruence in the Low Partner Effort condition, that is, participants invested more effort in the Incongruent condition than in the Congruent condition. Accordingly, the credible values of the difference of High Congruent and High Incongruent had a mode of 0.285 and a 95% HDI that extended from 0.207 to 0.34; zero was deemed not credible. The credible values of the difference of Low Congruent and Low Incongruent had a mode of -0.428 and a 95% HDI that extended from -0.487 to -0.342; zero was deemed not credible.

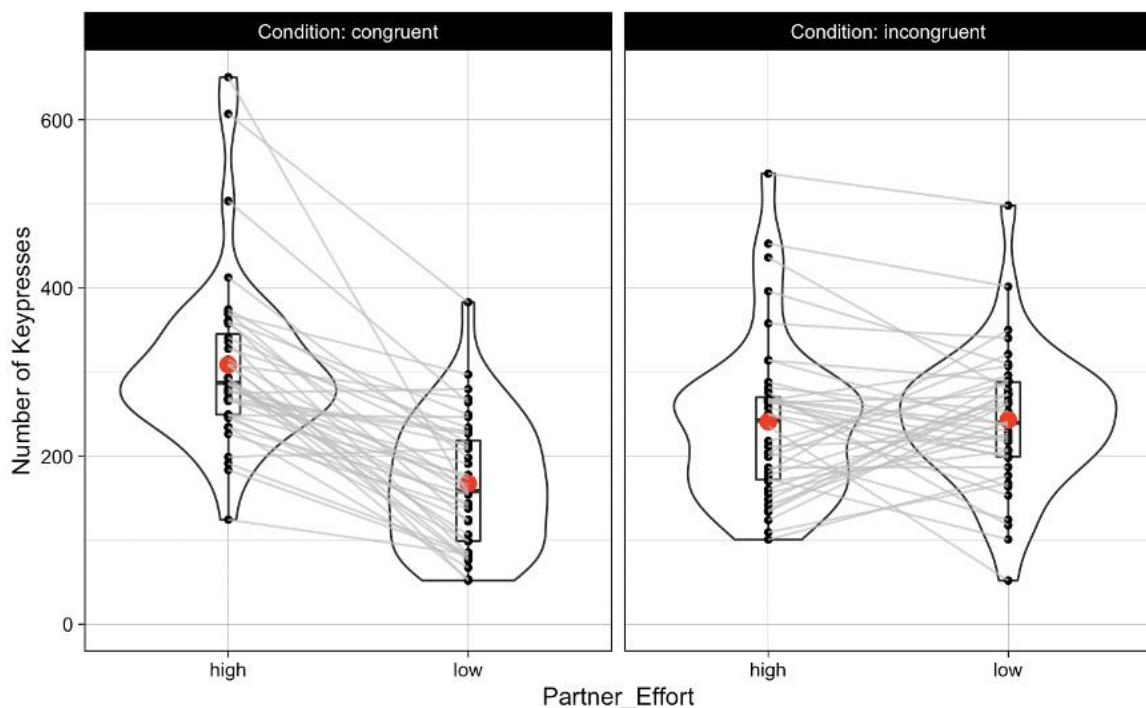


Figure 4: Participants' effort investment in the form of keypresses across conditions. Each black dot represents one participant's effort investment in the respective condition and the gray line connects one's effort investment in the High and Low Partner's Effort conditions within the respective Congruence condition. In each boxplot, horizontal lines indicate medians, and red circles indicate means.

Although in the Incongruent condition we did not find any difference between the High and Low Partner's Effort conditions at the group level, participants' effort investments in the Incongruent condition suggested that there is a difference at the individual level. Specifically, there appears to be a subset of participants who invested more effort in the Low Partner Effort condition than in the High Partner Effort condition (Environment-directed effort calibration group), while there appears to be a distinct subset of participants who invested more effort in the High Partner Effort condition than in the Low Partner Effort condition (Relationship-directed effort calibration group) (see **Figure 5**). To probe this, as an exploratory analysis, we analyzed the data of both subsets of participants separately by applying the same pre-registered Bayesian model. The results of the Environment-directed effort calibration group revealed a main effect of Partner Effort, no main effect of Congruence, and an interaction. Accordingly, the credible values of the difference of Partner Effort had a mode of 0.21 and a 95% HDI that extended from 0.126 to 0.273; zero was deemed not credible. The credible values of the difference of Congruence of Reward Structure had a mode of -0.0703 and a 95% HDI that extended from -0.131 to 0.007; zero was deemed credible. The credible values of the difference of differences had a mode of 1.25 and a 95% HDI that extended from 1.08 to 1.36; zero was deemed not credible. Moreover, the results revealed a simple effect of Partner Effort in the Congruent condition, that is, participants invested more effort in the High Partner Effort condition than in the Low Partner Effort condition, and a simple effect of Partner Effort in the Incongruent condition, that is,

participants invested more effort in the Low Partner Effort condition than in the High Partner Effort condition. Accordingly, the credible values of the difference of High Congruent and Low Congruent had a mode of 0.823 and a 95% HDI that extended from 0.717 to 0.917; zero was not deemed credible. The credible values of the difference of High Incongruent and Low Incongruent had a mode of -0.419 and a 95% HDI that extended from -0.51 to -0.307; zero was deemed not credible. The results also revealed a simple effect of Congruence in the High Partner Effort condition, that is, participants invested more effort in the Congruent condition than in the Incongruent condition, and a simple effect of Congruence in the Low Partner Effort condition, that is, participants invested more effort in the Incongruent condition than in the Congruent condition. Accordingly, the credible values of the difference of High Congruent and High Incongruent had a mode of 0.542 and a 95% HDI that extended from 0.463 to 0.655; zero was deemed not credible. The credible values of the difference of Low Congruent and Low Incongruent had a mode of -0.671 and a 95% HDI that extended from -0.772 to -0.575; zero was deemed not credible.

The results of the Relationship-directed effort calibration group revealed a main effect of Partner Effort, a main effect of Congruence, and an interaction. Accordingly, the credible values of the difference of Partner Effort had a mode of 0.452 and a 95% HDI that extended from 0.386 to 0.524; zero was deemed not credible. The credible values of the difference of Congruence of Reward Structure had a mode of -0.0856 and a 95% HDI that extended from -0.152 to -0.0161; zero was deemed not credible. The credible values of the difference of differences had a mode of 0.234 and a 95% HDI that extended from 0.0719 to 0.343; zero was deemed not credible. Moreover, the results revealed a simple effect of Partner Effort in the Congruent condition, that is, participants invested more effort in the High Partner Effort condition than in the Low Partner Effort condition, and a simple effect of Partner Effort in the Incongruent condition, that is, participants invested more effort in the High Partner Effort

condition than in the Low Partner Effort condition. Accordingly, the credible values of the difference of High Congruent and Low Congruent had a mode of 0.558 and a 95% HDI that extended from 0.463 to 0.65; zero was not deemed credible. The credible values of the difference of High Incongruent and Low Incongruent had a mode of 0.352 and a 95% HDI that extended from 0.24 to 0.435; zero was deemed not credible. The results also revealed no simple effect of Congruence in the High Partner Effort condition, and a simple effect of Congruence in the Low Partner Effort condition, that is, participants invested more effort in the Incongruent condition than in the Congruent condition. Accordingly, the credible values of the difference of High Congruent and High Incongruent had a mode of 0.0191 and a 95% HDI that extended from -0.0745 to 0.114; zero was deemed credible. The credible values of the difference of Low Congruent and Low Incongruent had a mode of -0.208 and a 95% HDI that extended from -0.289 to -0.0909; zero was deemed not credible.

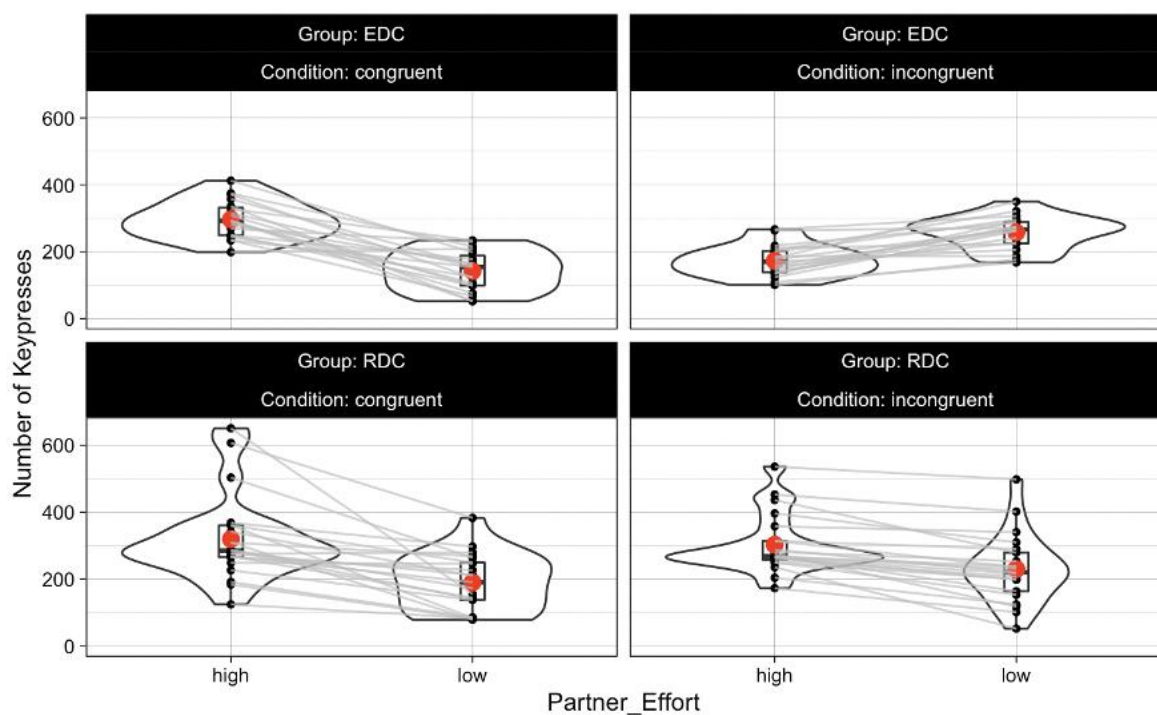


Figure 5: Participants' effort investment in the form of keypresses across conditions, split into two groups. The environment-directed effort calibration group (EDC) exhibits a change

from effort matching to inverse effort matching when the reward structure is incongruent rather than congruent. The relationship-directed effort calibration group (RDC) exhibits no such change. Each black dot represents one participant's effort investment in the respective condition, and the gray line connects each participant's effort investment in the High and Low Partner's Effort conditions within the respective Congruence of reward structure condition. In each boxplot, horizontal lines indicate medians, and red circles indicate means.

Experiment 3

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study.

Method

Participants. Using G*power (Faul, Erdfelder, Buchner, & Lang, 2009), we determined that a sample size of 20 participants provides 80% power to detect an effect size of $d = 0.66$ or greater in a paired-sample t-test with a 5% false-positive rate. We followed the pre-registered exclusion criteria: accordingly, we excluded 9 participants who failed the belief manipulation check at the end of the experiment (2 participants said that „My partner thought that the available reward value was always the same for them and for me.”; 5 participants said that „My partner thought that the available reward value was in one block the same, in another block the opposite for them and for me. ”; 2 participants said that „I don't remember what my partner thought about the available reward value.”) and we excluded 1 participant because we reached the target sample size of 20. The sample includes twenty individuals (14 female, $M_{age} = 26.5$ years, $SD_{age} = 3.713$ years). We did not exclude any data point from the analysis. Participants carried out the experiment in pairs; members in each pair did not know each other prior to participation. Participants were recruited through Central European University's Research Participation System (developed by SONA Systems;

<https://www.sona-systems.com/default.aspx>) in the Vienna area, were naïve to the purpose of the study, and reported normal or corrected to normal vision. All participants gave their informed written consent prior to the experiment and received gift vouchers for their participation. The experiment was conducted in accordance with the Declaration of Helsinki and was approved by the (PREBO) Psychological Research Ethics Board.

Apparatus and stimuli. The apparatus and stimuli were identical to that of Experiment 1.

Procedure. The procedure was identical to that of Experiment 1 except for two modifications. After the tutorials, participants had a familiarization phase with 4 trials in the Congruent condition and 4 trials in the Incongruent condition (they were counterbalanced and identical to the conditions of the Congruence manipulation of Experiment 1). Then, in the test phase, participants had 10 trials in the Uncertain condition.

Design. In a within-subject design experiment, participants were informed that their partner always believed that they were in an incongruent reward structure and that the partner believed that the participants had the same belief as them (i.e., partner). Moreover, participants were informed that, in fact, they would never know whether they were in a Congruent or Incongruent condition (Uncertain condition). We manipulated the virtual partner's effort investment: sometimes their partners invested a high level of effort (High Partner Effort condition), and sometimes they invested a low level of effort (Low Partner Effort condition). The dependent measure was identical to that of Experiment 1.

Data preparation and analysis. We prepared and analyzed the data in rStudio (RStudio Team, 2016) using R 4.0.0 (R Core Team, 2020), the tidyverse (v1.3.0; Wickham et al., (2019), the rjags (v4-10; Martyn Plummer, 2019) and the runjags (v2.0.4-6; Matthew J. Denwood, 2016) packages.

For the Bayesian data analyses, we decided to use parameter estimation instead of model comparison because parameter estimation provides an explicit posterior distribution on the parameters and so it provides more meaningful information than model comparison (Kruschke, 2015). We used a noncommittal broad prior on the parameters so that the prior had minimal influence on the posterior. We used Markov chain Monte Carlo (MCMC) techniques to generate representative credible values from the joint posterior distribution on the parameters. Three chains were initialized, well burned in (for 1,000 steps), and a total of 30,000 steps were saved. The chains were checked for convergence and autocorrelation and run long enough to produce an effective sample size (ESS) of at least 10,000 for all of the reported results. This yielded a stable and accurate representation of the posterior distribution on the parameters. See the reproducible scientific report for details.

Results

To examine the effect of Partner's Effort on participants' effort investment in the form of keypresses, we planned to perform a paired-sample t-test and a Bayesian analysis, and pre-registered them as the planned analyses. Prior to conducting this analysis, we performed a Shapiro-Wilk test on the difference of participants' effort investment between the conditions and it did not show evidence of non-normality (High Partner Effort ($M=308$, $Mdn=305$, $SD=109$); Low Partner Effort ($M=260$, $Mdn=264$, $SD=125$); $W=0.922$, $p=0.108$) (see **Figure 6**). Because the assumption of normality was met, we could perform a paired-sample t-test as we had pre-registered. The results revealed a significant effect of Partner Effort, $t(19) = 3.27$, $p < 0.00407$, $d = 0.73$. We also analyzed the data with Bayesian methods with the pre-registered model. We used a generalized linear mixed model, in which the predicted value is described as negative binomial distributed around a linear combination of categorical predictors (Partner's Effort, random effect of participant and random slopes of condition nested within participant) mapped to the central tendency of the predicted value via

the exponential function. The results revealed an effect of Partner Effort. Accordingly, the credible values of the difference of Partner Effort had a mode of 0.235 and a 95% HDI that extended from 0.165 to 0.33; zero deemed not credible.

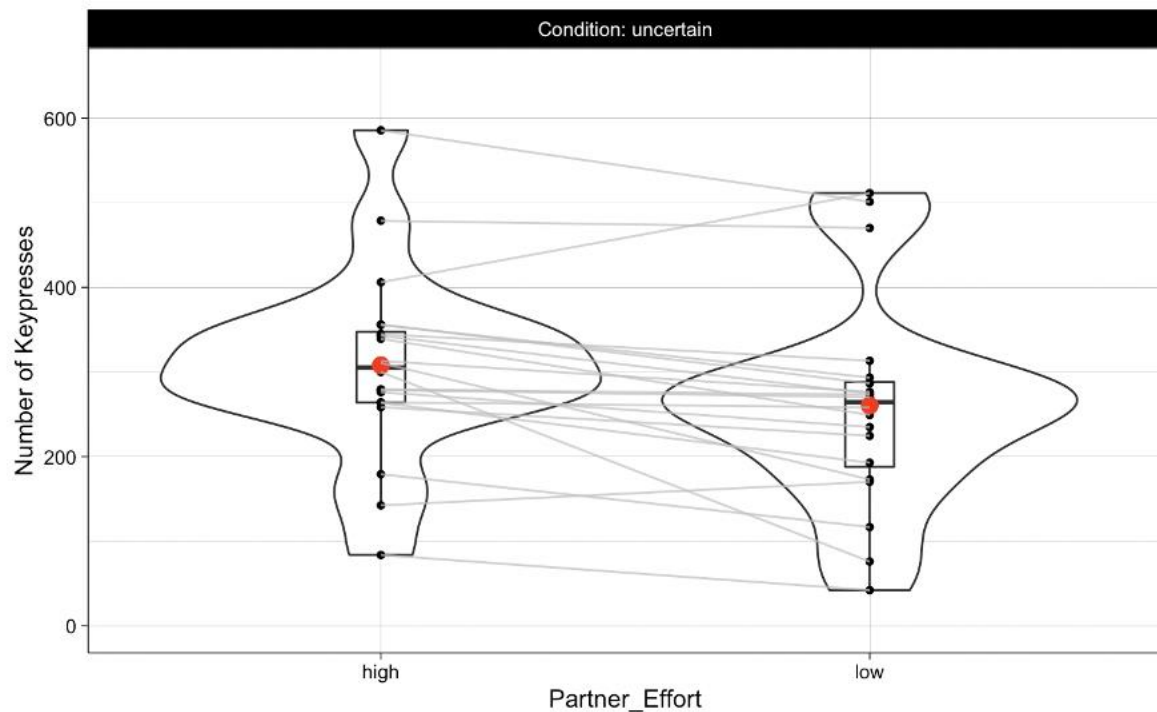


Figure 6: Participants' effort investment in the form of keypresses across conditions. Each black dot represents one participant's effort investment in the respective condition and the gray line connects one's effort investment in the High and Low Partner's Effort conditions. In each boxplot, horizontal lines indicate medians, and red circles indicate means.

General Discussion

A growing body of empirical work suggests that the perception or anticipation of a partner's effort modulates effort-based decision-making in the context of joint action (Chennells & Michael, 2018; Jackson and Harkins, 1985; Székely & Michael, 2018; Török, Pomiechowska, Csibra & Sebanz, 2019; Strachan & Török, 2020). In the current study, we investigated the hypothesis that people calibrate their effort investment in joint action with

the ultimate goal of attracting and keeping good collaboration partners (*The relationship-directed effort calibration hypothesis*) and that the proximal psychological motive that drives them to do so is a preference for fairness (*The equity through effort calibration hypothesis*). Across three experiments, we tested these hypotheses and differentiated them from alternative explanations of why people match their partners' effort. Specifically, in Experiments 1 and 2, we differentiated the relation-directed effort calibration hypothesis from the hypothesis that people may use their partner's effort costs as information to infer the value of opportunities afforded by their environment, which may lead them to adjust their effort investment as a function of the inferred value (*The environment-directed effort calibration hypothesis*). In Experiment 1, we found support for the relationship-directed calibration hypothesis in one subgroup and we found support for the environment-directed effort calibration hypothesis in a distinct subgroup. However, with respect to each of these subgroups, there is an alternative explanation which we were not able to rule out: namely, that participants within the different subsets exhibited the observed patterns in order to appear competent (*The appearance of competence hypothesis*). Experiment 2 was designed to rule this out as an alternative explanation of the subgroup that exhibited environment-directed effort calibration – i.e., this subgroup of participants may have inferred that their partner was aware that the reward structures were incongruent in the Incongruent condition, and may accordingly have invested greater effort in the Low Partner Effort condition and less effort in the High Partner Effort condition in order to demonstrate competence and efficiency to their partner. To address this, in Experiment 2, participants were informed that their partner always believed that they were in a congruent reward structure, and we found clear support for both the relationship-directed and the environment-directed effort calibration hypotheses. Having found evidence for the relationship-directed effort calibration hypothesis in Experiments 1 and 2, we next turned our attention to the proximal psychological motives underpinning these

effects, and specifically to testing the hypothesis that when people expect to share the reward of the joint task equally, people ensure fairness by calibrating their effort investment such as to reduce inequity with respect to joint action partners' effort investment (The equity through effort calibration hypothesis). Experiments 1 and 2 do not directly support this hypothesis because they were not designed to rule out the appearance of competence hypothesis. To address this, Experiment 3 provided evidence of relationship-directed effort calibration, but in a context in which it could uniquely be explained by the equity through effort calibration hypothesis – i.e. in which the appearance of competence hypothesis could be ruled out.

This research offers the first evidence for functional explanations of why the perception of a partner's effort modulates effort-based decision-making in joint action and thereby contributes to attaining a fuller understanding of the role of effort and effort perception in human cooperative interactions. First, our findings demonstrate that people calibrate their effort investment in joint action with the ultimate goal of attracting and keeping good collaboration partners and that the proximal psychological motive that drive them to do so is a preference for fairness. This provides a valuable addition to existing research on the sense of fairness. Our findings provide evidence that the sense of fairness leads people not only to distribute resources according to individual effort costs but to distribute effort costs according to the expected reward distribution as well.

Second, our findings show that people use others' investment of effort to infer the value of opportunities afforded by their environment, and that they adjust their effort accordingly. These findings are consistent with a large body of work on naïve utility calculus suggesting that human beings from early infancy assume that other agents act to maximize subjective utility (Jara-Ettinger, Gweon, Tenenbaum & Schulz, 2016).

The findings also provide a valuable addition to existing research on how people prioritize overall efficiency over a consideration of fairness. Recently, Strachan & Török (2020) found evidence that in joint action people prioritize joint efficiency over fairness. However, in their experiments the effort costs were small for participants, and the authors identified the possibility that fairness may affect decision-making more when there are substantial action costs. The current research supports this conjecture by demonstrating that when the costs are higher, some participants are more strongly motivated by fairness than by efficiency considerations. Moreover, by identifying distinct subgroups that are more strongly motivated by the one than the other, they raise the intriguing possibility that there may be substantial individual differences with respect to the relative strength of these motives. Further research is needed in order to catalog and to explain these individual differences.

One limitation of the current research is that in all experiments we operationalized the partner's and participants' effort as the physical effort investment of repeated keypresses. Future research should generalize these findings by investigating whether cues of a partner's cognitive or physical effort elicit effort matching on different effort measures.

Open practices

This project was pre-registered prior to data collection [Experiment 1: https://osf.io/up2sw/?view_only=1ac485fbb976436fad28c1a40b3d2a95 ; Experiment 2: https://osf.io/zt5d3/?view_only=b49366807cb94be7a786b8e7b9847941 ; Experiment 3: https://osf.io/rptw9/?view_only=c1540add34744cd285e251ee6c47600f]. The reproducible scientific reports (data and analysis code) are available in an online repository here [https://osf.io/cj64t/?view_only=a3697e5d4a1847ea92095af20e40cc59].

Chapter 4. In It Together: Evidence of a Preference for the Fair Distribution of Effort in Joint Action

Mutually beneficial cooperation is widespread in nature. For example, Tai chimpanzees (*Pan Troglodytes*) hunt in groups (Boesch, 1994). Keas (*Nestor notabilis*) are able to negotiate the distribution of roles in a task that requires a lever to be pushed down in order to release food from a box (Tebbich, 1996). Three-year-old human children jointly move a block to obtain marbles by pulling both ends of the rope simultaneously (Hamann, Bender and Tomasello, 2014). In all of these examples, mutualistic interaction poses a challenge insofar as it generates benefits which must then be distributed among the individuals involved. One way to do so is to divide the benefit of cooperation according to the “law of the strongest”. In such a power struggle, the dominant individual can unilaterally determine a division of resources and both the dominant and dominated individual should pursue the income maximizing strategies. This means that the dominant individual should offer the minimum possible amount and the dominated individual should accept whatever they are offered because accepting it brings greater benefits than being left without a social interaction. And indeed, this is what we observe in chimpanzees and keas, but not in humans. Specifically, when Tai chimpanzees participate in group hunting, it is dominance, not hunting time, which determines how much meat each individual obtains (Boesch, 1994), and when keas cooperate in the aforementioned lever-pushing task, it is the dominant individual who obtains the reward on any given trial (Tebbich, 1996).

But the law of the strongest is not the only way to govern the distribution of benefits generated by mutualistic interaction. To the extent that partner choice exists and there are alternative cooperative opportunities for dominated individuals, those dominated individuals are less willing to tolerate inequity imposed by dominant individuals, thereby restricting the level of inequity that dominants can impose. For example, André and Baumard (2011) modeled the evolution of the division of the benefits of cooperation between two individuals

in an ultimatum game, in which the dominant individual makes an offer that the dominated individual can only accept or refuse. Crucially, the dominated individual always had the possibility of entering into another identical interaction with a new partner by refusing to accept the offer. They found that when the dominant or dominated status of an individual in each interaction is chosen at random and the cost of postponing the interaction is very small, then each individual gets almost half of the resource. Debove, Baumard and André (2015) went a step further by demonstrating with a similar evolutionary model that equal divisions can evolve even when some individuals are inherently stronger than others in the population. They showed that as long as the cost of changing partners is not too high the most important factor that determines individuals' payoffs is not the average of their outside options, but their best alternative opportunities for cooperation. Moreover, in another study Debove, Baumard and André (2017) demonstrated that when individuals differ in their productivity, proportional divisions evolve because individuals can bargain based on their outside options – that is, on their opportunity costs. In this model, a high-productivity individual could produce 2 units of a resource while a low-productivity individual could produce 1, which meant that a high-productivity individual had the possibility to produce 4 by working together with a high-productivity individual, or to produce 3 by working together with a low-productivity individual. Therefore, a high-productivity individual did not interact with a low-productivity individual unless the low-productivity individual was willing to compensate them for their opportunity costs by letting them keep 2 out of the 3 units produced together – the quantity a high-productivity individual would have earned by working together with another high-productivity individual. The authors use this as a basis for an ultimate explanation of our sense of fairness, arguing that such bargaining over opportunity costs in the context of partner selection may have unfolded over the course of human evolution, producing a psychological mechanism now operative at the proximal level: a preference for

divisions of rewards that are proportional to contributions. Thus, our sense of fairness implies a preference not necessarily for equality but for equity.

While the arguments for social selection of a preference for equity is convincing, the underlying psychological mechanisms are not well understood. Most importantly, it is not clear what inputs are taken into account in determining equitable distribution. In other words, what contributions to cooperative interactions does the sense of fairness track? One may speculate that a sense of fairness tracks those parameters which most strongly determine the outcome of mutually beneficial interactions in general, such as the investment of material resources, effort, time and skill. And indeed, there is experimental evidence to support this. For example, Cappelen, Hole, Sorensen and Tungodden (2007) found that most people distributed resources according to material resources invested (money), but discounted those parts of the outcome that had arisen due to luck.

In the recent empirical literature, there has been a special focus on effort as a form of contribution to which the sense of fairness is particularly sensitive. For example, Frohlich, Oppenheimer and Kurki (2004) found that when participants were placed in one room and had to proofread a text to correct spelling errors for joint rewards, they divided their collectively earned rewards proportionally to individual effort costs in a subsequent dictator game. Similarly, recent studies have shown that three-years old children take effort costs into account to achieve a fair distribution of joint action outcomes (Hamann, Bender and Tomasello, 2014; Kanngiesser and Warneken, 2012). In addition, Sloane, Baillargeon and Premack (2012) found that even 21-month-olds infants expected an experimenter to distribute rewards among two individuals proportional to their effort costs. Taken together, there is good evidence showing that people are highly sensitive to the distribution of effort costs and that reward distribution is governed by a sense of fairness in a way that takes effort investments into account.

And yet there has been no study testing whether people distribute effort costs according to the expected reward distribution. This is an important gap in the literature: insofar as the sense of fairness evolved to ensure being recruited as a partner in mutually advantageous cooperative interactions without the risk of being taken advantage of by others, we should expect that it is well adapted to situations in which the outcome of a collaborative venture is not divisible or uncertain. For example, hunting and foraging in ancestral environments were uncertain endeavors, and they may not have yielded any outcome to distribute at all. Similarly, the benefits of building a shelter or tidying up together may not produce any divisible outcome. In such instances, the only way to share the costs and benefits of a joint action fairly is to invest effort equally. Thus, the sense of fairness should lead one not only to distribute resources according to individual effort costs but to distribute effort costs according to the expected reward distribution as well.

This line of reasoning motivates the hypothesis that when people expect to share the reward of the joint task equally, we should expect them to ensure fairness by calibrating their effort investment such as to reduce inequity with respect to joint action partners' effort investment (The *equity through effort calibration hypothesis*). To test this, we implemented a paradigm in which participants traded off effort costs against reward – that is, participants could choose to invest either no effort for a low reward, or some (variable) greater amount of effort in order to obtain an equal or greater (variable) reward (Hartmann, Hager, Tobler & Kaiser, 2013). Before making their decision, they observed as their partner performed an effort task. Sometimes participants were rewarded jointly (Joint condition), and sometimes they were rewarded separately (Parallel condition). We examined how the perception of a partner's effort modulated effort-based decision-making in joint action depending on whether participants were in a joint or separate reward structure. Rational choice theory predicts that participants should trade off effort costs against reward similarly in both conditions. After all,

the perception of a joint action partner's effort should not lead to any changes in one's effort investment - except insofar as the partner's effort level influences task demands or rewards. People should invest effort according to the expected reward value of the task. However, if the equity through effort calibration hypothesis is correct, then the partner's effort investment should boost participants' willingness to choose their own effortful option over the no effort option in the Joint condition but not in the Parallel condition.

Of course, there are also other possible reasons why people may be willing to adjust their effort investment in the direction of their partner's effort investment. One possibility is that the function of effort matching is to allocate one's effort costs optimally such as to obtain maximal rewards for minimal effort costs. If one is uncertain about the reward structure of the environment, one may use others' investment of effort to infer the value of the activity. Therefore, people may use their partner's effort costs as information to infer the value of opportunities afforded by their environment, which may lead them to adjust their effort investment as a function of the inferred value (*The environment-directed effort calibration hypothesis*). It is particularly important to distinguish between these explanations insofar as recent studies have shown that people do indeed make use of perceptual cues to infer a partner's investment of effort and calibrate their own effort investment accordingly (Székely & Michael, 2018; Chennells & Michael, 2018) – however, these studies did not explore why people do so. To this end, we also manipulated participants' information about the reward: sometimes they knew the exact reward value of the trial (Reward Known condition), sometimes they didn't (Reward Unknown condition). The environment-directed effort calibration hypothesis generates the prediction that participants would adjust their effort investment more in the direction of their partner's effort investment in the Reward Unknown condition than in the Reward Known condition.

In the two pre-registered experiments presented here, we aimed to test the equity through effort calibration hypothesis by implementing scenarios in which it would predict patterns of participant behaviour that could not be explained by the environment-directed effort calibration hypothesis and by other alternative hypotheses. In Experiment 1 we manipulated 1) whether participants were rewarded jointly or separately, and 2) the information participants knew about the available reward values. The *equity through effort calibration hypothesis* predicts that participants would match their partner's effort more in the Joint condition than in the Parallel condition, while it does not predict any difference between the Reward Known and Reward Unknown conditions; the *environment-directed effort calibration hypothesis* generates the opposite set of predictions. In Experiment 2, we aimed to further test the equity through effort calibration hypothesis by ruling out alternative explanations for effort matching. To this end, we introduced two levels of possible effort investment (High and Low) for the partner as well as for the participant. This made it possible to specifically test whether participants would not only choose to invest effort when their partner had done so, but whether they would choose to invest a high level of effort rather than a low level of effort specifically when their partner had also done so. We predicted participants would differentiate between different levels of a partner's effort investment providing support for the equity through effort calibration hypothesis.

Experiment 1

Method

Participants. Using G*power (Faul, Erdfelder, Buchner, & Lang, 2009), we determined that a sample size of 20 would provide 90% power for detecting a medium-sized effect.

Accordingly, we initially planned on a sample size of 20. Anticipating a dropout rate equivalent to other similar studies carried out in the same lab, we recruited 24 participants, all who ultimately did participate. One individual was excluded from analyses because of

computer error, leaving a sample of 23 (i.e. 23 participants: 12 female, $M_{age} = 27.30$ years, $SD_{age} = 4.75$ years) participating in the study. Participants carried out the experiment in pairs; members in each pair did not know each other prior to participation. All participants were recruited through Central European University's Research Participation System (developed by SONA Systems; <https://www.sona-systems.com/default.aspx>) in the Budapest area, were naïve to the purpose of the study, and reported normal or corrected to normal vision. All participants gave their informed written consent prior to the experiment and received gift vouchers for their participation. Participants were debriefed about the hypotheses and the use of deception after each experimental session. The experiment was conducted in accordance with the Declaration of Helsinki and was approved by the (EPKEB) United Ethical Review Board for Research in Psychology.

Apparatus and stimuli. The experiment was displayed on a 13-inch computer screen (resolution: 2560×1600 pixels, refresh rate: 60 Hz). The program for the experiment was written in Python (Peirce, 2007). The algorithm for executing the partner's part of the task was programmed to behave in a human-like manner: sometimes it speeds up or slows down.

The captchas, which were presented to participants to indicate their partner's investment of effort, differed in their difficulty, as depicted in Figure 1. The easiest captchas consisted of 3 characters and were deciphered in 6 s, the second level captchas consisted of 6 characters and were deciphered in 11 s, the third level captchas consisted of 10 characters and were deciphered in 14 s, while the most difficult captchas consisted of 12 characters and were deciphered in 16 s. These stimuli were validated in an online study, in which people consistently rated the longer deciphering duration as more effortful (Székely & Michael, under review).

3 characters	6 characters	10 characters	12 characters
***	*****	*****	*****

Figure 1: Captchas. During the captcha phase, strings of asterisks appeared on the screen to indicate that the partner was solving a captcha, with shorter strings implying a low effort requirement and longer strings implying a higher effort requirement.

Procedure. Participants were first introduced to another participant in the waiting area, whom they were told would be their partner for the experiment, and who would be playing in the adjacent room (in fact, both of them were playing with a virtual partner controlled by the computer, so that maximum experimental control could be maintained). They were informed that their task was to collect points together with their partner. Each point increased the probability of getting a bonus at the end of the experiment.

All participants were led to believe that their partner voluntarily chose between an easy and difficult captcha in order to unlock each round (see **Figure 2**). They were informed that if their partner chose the difficult captcha over the easy captcha, then the available reward value would be larger than if their partner chose the easy captcha over the difficult captcha. On each round, they observed the process of deciphering the captcha. Then, they were informed how many points their partner had earned. Next, participants could choose between a *no effort/1 point* and a *some effort/some reward* option. With respect to the latter option, both physical effort (10/50/90/100 keypresses) and reward magnitude (1/2/3/4/5 points) were independently manipulated. It is important to note that we designed the experiment in such a way that the partner's perceived effort investment - in the form of

solving a captcha of various length (3/6/10/12 characters) - always correlated with participants' required effort investment (10/50/90/100 keypresses) if they chose the *some effort* option. If participants chose the some effort option, they had to produce the required number of keypresses. Then, they were informed how many points they had earned.

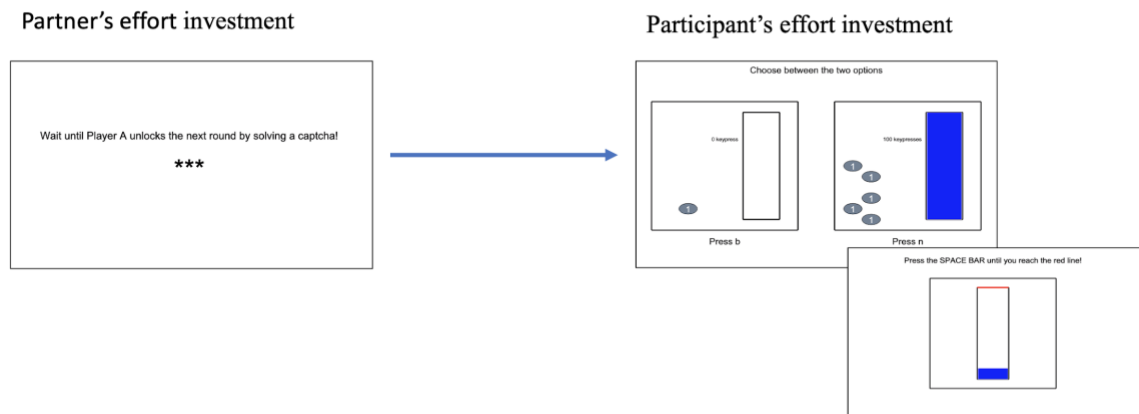


Figure 2: Trial structure. Each trial consisted of a captcha phase, followed by a round of the effort discounting task. In the captcha phase, a video was presented in which stars progressively appeared to indicate that the partner was solving a captcha, and finally the completed captcha key was displayed. This unlocked a round of the effort discounting task where participants could choose between a *no effort/1 point* and a *some effort/some reward* option. If participants chose the effortful option, they had to produce the required number of keypresses.

In a two-way within-subject design, participants were measured in four conditions. In the Joint condition, participants worked together with their virtual partner with a joint account and their points were evenly divided between them; in the Parallel condition, they collected points separately. In the Reward Known condition, participants knew the exact reward value of the round; while in the Reward Unknown condition, they didn't. Specifically, participants were told that in the Reward Known condition, they (i.e., participants) would be informed

about the values of their rewards and their partner's rewards, but their partner would not have any information about this. In contrast, in the Reward Unknown condition, participants were told that their partner would be informed about the values of the rewards for both of them, but they (i.e., participants) would not have any information about this. The experiment consisted of 80 rounds in total, there were 20 rounds in the Joint and Reward Known condition, 20 rounds in the Joint and Reward Unknown condition, 20 rounds in the Parallel and Reward Known condition, and 20 rounds in the Parallel and Reward Unknown condition, counterbalanced across participants.

The experiment was preceded by four tutorials. The first three tutorials introduced participants to the keypress task and the choice they would face on each round. The partner's task was introduced in the last tutorial; here, the captcha was 6 characters long, and took 12 s to decipher.

Data preparation and analysis. On each trial, we measured participants' choices between the no effort and the some effort option. This enabled us to calculate the proportion of choosing the effortful option. We prepared and analyzed the data in rStudio (RStudio Team, 2016) using R 4.0.0 (R Core Team, 2020), the *tidyverse* (v1.3.0; Wickham et al., 2019), the *rjags* (v4-10; Martyn Plummer, 2019) and the *runjags* (v2.0.4-6; Matthew J. Denwood, 2016) packages.

For the Bayesian data analyses, we used a noncommittal broad prior on the parameters so that the prior had minimal influence on the posterior. We used Markov chain Monte Carlo (MCMC) techniques to generate representative credible values from the joint posterior distribution on the parameters (Kruschke, 2015). Three chains were initialized, well burned in (for 1,000 steps), and a total of 30,000 steps were saved. The chains were checked for convergence and autocorrelation and run long enough to produce an effective sample size

(ESS) of at least 10,000 for all of the reported results. This yielded a stable and accurate representation of the posterior distribution on the parameters.

Results

To examine the effect of Jointness and Reward Knowledge on participants' proportion of choosing the effortful option, we planned to perform a repeated measures ANOVA, and pre-registered this as the planned analysis. Prior to conducting this analysis, we performed a Shapiro-Wilk test on all four conditions and two of them showed evidence of non-normality (Joint Known ($M=0.69$, $Mdn=0.70$, $SD=0.18$), $W = 0.937$, $p = 0.158$; Joint Unknown ($M=0.82$, $Mdn=0.95$, $SD=0.25$), $W = 0.733$, $p = 0.0000389$; Parallel Known ($M=0.72$, $Mdn=0.75$, $SD=0.20$), $W = 0.950$, $p = 0.29$; Parallel Unknown ($M=0.73$, $Mdn=0.90$, $SD=0.32$), $W = 0.810$, $p = 0.000554$). Because the assumption of normality was not met, we could not perform a repeated measures ANOVA as we had pre-registered. Therefore, we decided to analyze the data with Bayesian methods. We used a generalized linear mixed model, in which the predicted value is described as Bernoulli distributed around a linear combination of categorical predictors (Jointness, Reward Knowledge, random effect of participant and random slopes of condition nested within participant) mapped to a probability value via the logistic function. The results revealed no main effect of Jointness, a main effect of Reward Knowledge and an interaction effect between Jointness and Reward Knowledge on participants' choices (see **Figure 3**). Accordingly, the credible values of the difference of Joint and Parallel had a mode of 0.10 and a 95% HDI (the 95% highest density interval contains the most credible 95% of the values) that extended from -0.18 to 0.45. Thus, zero was deemed credible, meaning that there was main effect of Jointness. The credible values of the difference of Reward Known and Reward Unknown had a mode of -0.85 and a 95% HDI that extended from -1.24 to -0.55. Thus, zero was deemed not credible, meaning that participants chose the effortful option more in the Reward Unknown condition than in the

Reward Known condition. The credible values of the interaction effect between Jointness and Reward Knowledge had a mode of -0.73 and a 95% HDI that extended from -1.32 to -0.11. Thus, zero was deemed not credible, which indicates that there was an interaction between Jointness and Reward. Moreover, the results revealed no simple effect of Jointness in the Reward Known condition and a simple effect of Jointness in the Reward Unknown condition. Accordingly, the credible values of the difference of Joint Known and Parallel Known had a mode of -0.222 and a 95% HDI that extended from -0.612 to 0.105. Zero was deemed credible, which indicates the absence of a simple effect of Jointness in the Reward Unknown condition. The credible values of the difference of Joint Unknown and Parallel Unknown had a mode of 0.522 and a 95% HDI that extended from 0.0454 to 0.106. Thus, zero was deemed not credible, meaning that participants chose the effortful option more in the Joint condition than in the Parallel condition in the Reward Unknown condition. The credible values of the difference of Joint Known and Joint Unknown had a mode of -1.31 and a 95% HDI that extended from -1.78 to -0.836. Thus, zero was deemed not credible, meaning that participants chose the effortful option more in the Joint Unknown condition than in the Joint Known condition. The credible values of the difference of Parallel Known and Parallel Unknown had a mode of -0.562 and a 95% HDI that extended from -0.969 to -0.0572. Thus, zero was deemed not credible, meaning that participants chose the effortful option more in the Parallel Unknown condition than in the Parallel Known condition.

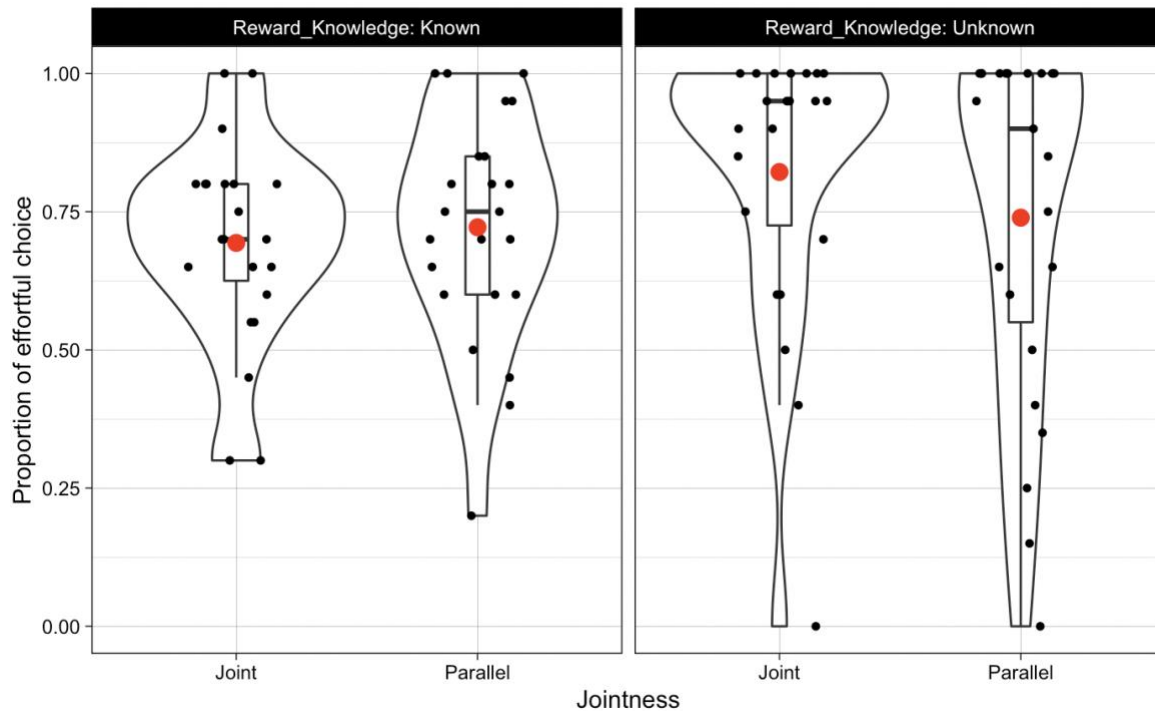


Figure 3. Proportion of effortful choice across conditions. Each black dot represents one participant's proportion of effortful choice in the respective condition. In each boxplot, horizontal lines indicate medians, and red circles indicate means. Importantly, participant's proportion of effortful choice corresponds to the proportion of trials in which participants had matched their effort to their partner's effort because whenever they chose the effortful option over the no effort option they adjusted their effort investment in the direction of the partner's effort investment.

In addition, as an exploratory analysis, we also examined whether participants traded off effort costs against rewards rationally and whether they were sensitive to both the effort costs and rewards which we manipulated in this setup (see **Figure 4** and **5**). In doing so, we analyzed the part of the data where the reward was known to participants with Bayesian methods. We used a generalized linear mixed model, in which the predicted value is described as Bernoulli distributed around a linear combination of categorical predictors (Jointness, Effort, Reward and random effect of participant) mapped to a probability value via the logistic function. The results revealed no main effect of Jointness, a main effect of

Effort, a main effect of Reward and no interaction effects between Jointness and Effort, between Jointness and Reward, between Effort and Reward, and between Jointness, Effort and Reward on participants' effortful choices. Accordingly, the credible values of the difference of Joint and Parallel had a mode of -0.382 and a 95% HDI that extended from -0.934 to 0.0356; zero was deemed credible. The credible values of the difference of 10 and 100 Effort levels had a mode of 3.32 and a 95% HDI that extended from 2.47 to 4.38; zero was deemed not credible, participants chose the effortful option less at higher levels of required effort. The credible values of the difference of 1 point and 5 points reward levels had a mode of -5.72 and a 95% HDI that extended from -6.79 to -4.86; zero deemed not credible, participants chose the effortful option more at higher levels of reward. The credible values of the interaction effect between Jointness and Effort had a mode of -0.616 and a 95% HDI that extended from -2.01 to 0.631; zero deemed credible. The credible values of the interaction effect between Jointness and Reward had a mode of 0.119 and a 95% HDI that extended from -0.919 to 1.35; zero deemed credible. The credible values of the interaction effect between Effort and Reward had a mode of -0.5 and a 95% HDI that extended from -2.73 to 1.44; zero deemed credible. The credible values of the interaction effect between Jointness, Effort and Reward had a mode of -0.0222 and a 95% HDI that extended from -1.59 to 1.47; zero deemed credible.

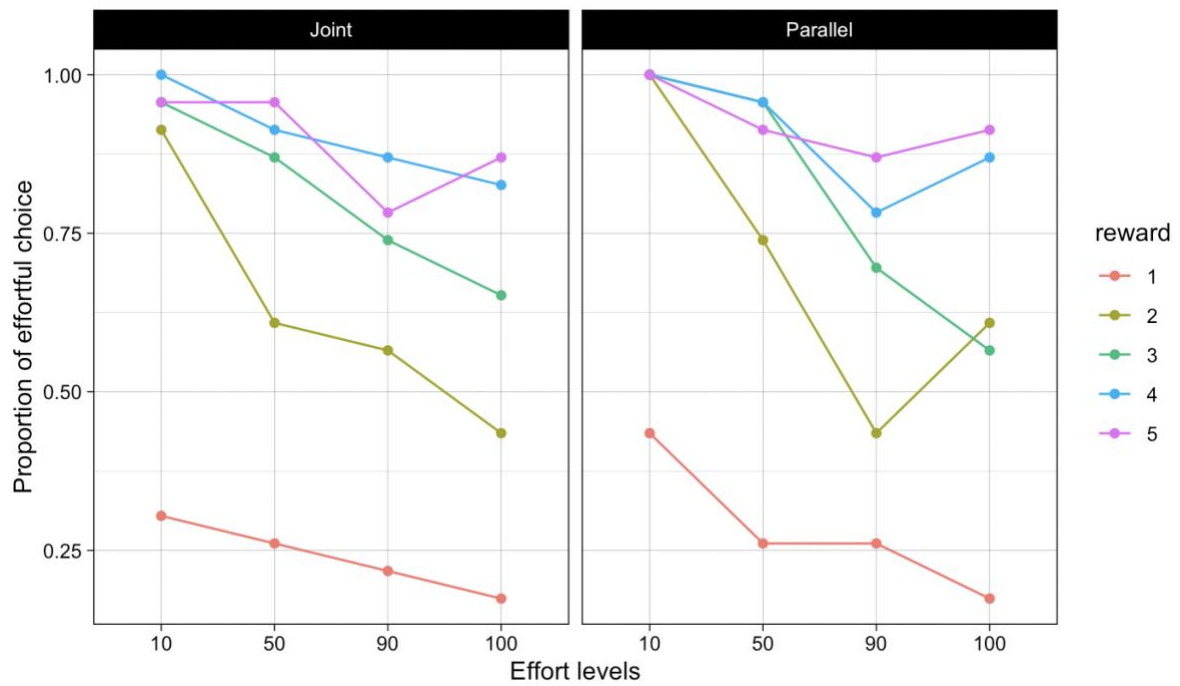


Figure 4. Group mean proportion of effortful choice for different rewards and effort levels in the Reward Known condition.

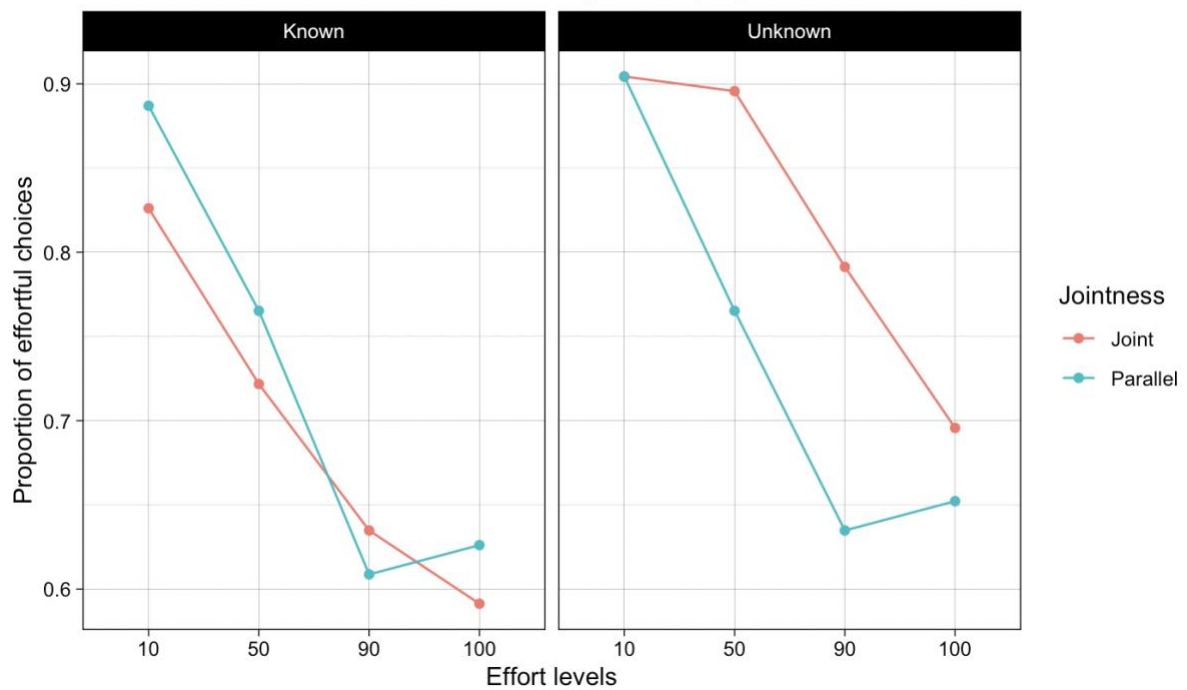


Figure 5. Group mean proportion of effortful choice for different effort levels across the four conditions.

Discussion

Our results are consistent with previous research on effort discounting (Chong et al., 2017; Hartmann et al., 2013). Importantly, the results confirm that participants traded off effort costs against reward rationally, and also that they were sensitive to both the effort costs and rewards which we manipulated in this setup.

As predicted by the environment-directed effort calibration hypothesis, we found a main effect of Reward Knowledge. Specifically, participants chose the effortful option over the no effort option more in the Reward Unknown condition than in the Reward Known condition. Importantly, whenever they chose the effortful option over the no effort option, they adjusted their effort investment in the direction of the partner's effort investment. This means that they matched their partner's effort more when they were uncertain about the value of opportunities afforded by their environment. This supports the environment-directed effort calibration hypothesis: people use others' effort costs as information to infer the reward value of the environment and this leads them to increase or decrease their effort investment as a function of the inferred reward value.

In contrast with the prediction generated by the equity through effort calibration hypothesis, we did not find a main effect of Jointness. However, we found an interaction effect between Jointness and Reward Knowledge. Specifically, we found that participants chose the effortful option over the no effort option more in the Joint condition than in the Parallel condition when the reward was unknown. In other words, in the Reward Unknown condition, participants matched their partner's effort more when they were interdependent than when they were independent. This provides partial support for the equity through effort calibration hypothesis.

On the other hand, in the Reward Known condition, participants unexpectedly chose the effortful option over the no effort option similarly in the Parallel condition and in the

Joint condition. In addition, we also observed that in the Parallel condition, participants exhibited an apparently irrational behavioral pattern. Although overall, participants in the Parallel condition traded off effort costs against monetary reward rationally – i.e., as the required effort investment increased, they chose the effortful option less – this relationship was not monotonic as expected by rational choice theory. Instead, they chose the effortful option more at the highest effort level than at the preceding effort level (see **Figure 5**). This pattern was not entirely absent in the Joint condition, but it was more prevalent in the Parallel condition (see **Figure 4**). Interestingly, this apparently irrational behavioral pattern can also be observed in the findings of Hartmann et al.'s (2013) - although less clearly than in our study. They do not attempt to explain it, and we will also refrain from speculating about it here. However, we do have one conjecture to explain why this pattern was suppressed in the Joint condition. This is based upon recent research establishing that in joint actions, people expect each other to act rationally, maximizing the utility of the joint action even if this comes at a cost to themselves or to their partner. For example, Török, Pomiechowska, Csibra & Sebanz (2019) found that people minimized joint effort by either increasing their own or their partner's individual effort in joint action. Building on these results, Strachan & Török (2020) found that in joint action people prioritized joint efficiency over individual efficiency and fairness. Drawing on this research, we may speculate that our participants acted more rationally in the Joint condition than in the Parallel condition because in the Joint condition, but not in the Parallel condition, their partner was also relying on them to act rationally. This conjecture may also help explain why we did not observe a main effect of Jointness: in the Reward Known condition, participants might have prioritized joint efficiency over a consideration of fairness. Crucially, in the Reward Unknown condition, where they could not prioritize joint efficiency over fairness, they matched their partner's effort more in the Joint condition than in the Parallel condition.

Experiment 2

The findings from Experiment 1 only provide partial support for the equity through effort calibration hypothesis. That is, participants matched their partner's effort more in the Joint condition than in the Parallel condition when the reward was unknown, but not when the reward was known. But there is also an alternative explanation for the effect of Jointness in the Reward Unknown condition. Previous work suggests that children are more willing to invest effort for shared goals compared to individual goals (Butler & Walton, 2014; Koomen, Grueneisen & Herrmann, 2020). Accordingly, participants may have invested more effort in the Joint Unknown condition than in the Parallel Unknown condition simply because they found acting together for shared rewards intrinsically more rewarding than acting separately. The reason why Experiment 1 did not directly differentiate between these two explanations is that, in Experiment 1, participants chose between a no effort and effortful option where the effort requirement associated with the effortful option was always matched with the partner's effort investment. Therefore, if they chose to remain engaged in the joint action, they simultaneously matched their partner's effort investment. We reasoned that if the effect observed in Experiment 1 reflects a preference for acting together, then participants should not differentiate between different levels of a partner's effort investment. In contrast, if the effect observed in Experiment 1 reflects a preference for fair distribution of effort costs, we should expect participants to differentiate between different levels of a partner's effort investment providing support for the equity through effort calibration hypothesis.

Method

Participants. Using G*power (Faul, Erdfelder, Buchner, & Lang, 2009), we determined that a sample size of 34 would provide 80% power for detecting a medium-sized effect.

We followed the pre-registered exclusion criteria: accordingly, we excluded the 14 participants who chose the more effortful option on more than 90% of all trials. The sample includes seventeen pairs of individuals (19 female, $M_{age} = 25.97$ years, $SD_{age} = 4.75$ years). The members in each pair did not know each other prior to participation. All participants were recruited through Central European University's Research Participation System (developed by SONA Systems; <https://www.sona-systems.com/default.aspx>) in the Budapest area, were naïve to the purpose of the study, and reported normal or corrected to normal vision. All participants signed informed consent prior to the experiment and received gift vouchers for their participation. The experiment was conducted in accordance with the Declaration of Helsinki and was approved by the (EPKEB) United Ethical Review Board for Research in Psychology.

Apparatus and stimuli. The experiment was displayed on a 13-inch computer screen (resolution: 2560×1600 pixels, refresh rate: 60 Hz). The program for the experiment was written in Python (Peirce, 2007). The algorithm for executing the partner's part of the task was programmed to behave in a human-like manner: sometimes it speeds up or slows down.

The captchas, which were presented to participants to indicate their partner's investment of effort, differed in their difficulty, as depicted in Fig. 5. The easy captchas consisted of 3 characters and were deciphered in 6 s, while the difficult captchas consisted of 12 characters and were deciphered in 16.

Procedure. Participants were first introduced to another participant in the waiting area, whom they were told would be their partner for the experiment, and who would be playing in the adjacent room (in fact, both of them were playing with a virtual partner controlled by the computer, so that maximum experimental control could be maintained). They were informed

that their task was to collect points together with their partner. Each point increased the probability of getting a bonus at the end of the experiment.

On each round, all participants first observed what they believed to be the process of their partner deciphering the captcha. Specifically, they were led to believe that their partner voluntarily chose between unlocking the round by solving a captcha or skipping the round. Then participants could choose between a *fixed small effort/1 point* and a *more effortful/2 points* option (see **Figure 6**). If participants chose the effortful option, they had to produce the required number of keypresses for joint reward.

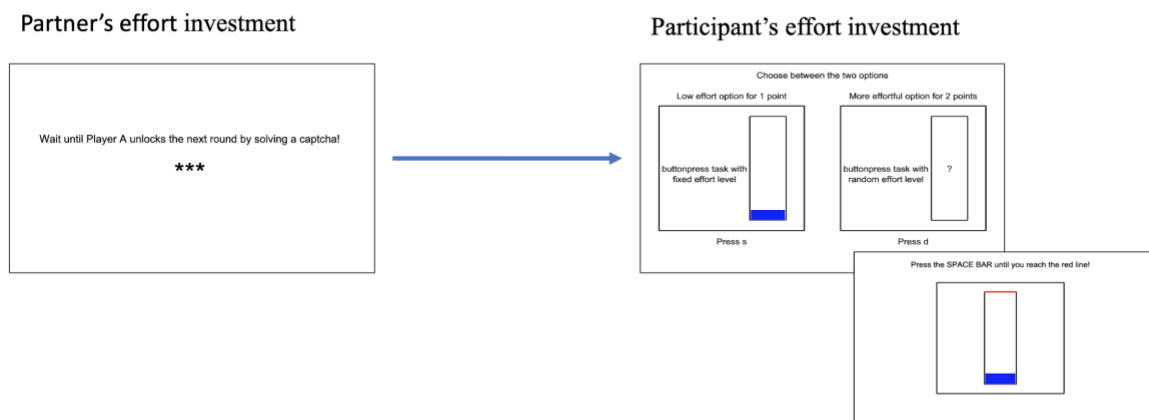


Figure 6: Trial structure. Each trial consisted of a captcha phase, followed by a round of the effort discounting task. In the captcha phase, a video was presented in which stars progressively appeared to indicate that the partner was solving a captcha, and finally the completed captcha key was displayed. This unlocked a round of the effort discounting task where participants could choose between a *fixed small effort/1 point* and a *more effortful/2 points* option. If participants chose the effortful option, they had to produce the required number of keypresses for joint rewards.

In a one-way repeated measures design, the experiment consisted of 40 rounds in total, 20 rounds in the High Perceived effort condition (in which the virtual partner took 16

seconds to complete the captcha that consisted of 12 characters), and 20 rounds in the Low Perceived Effort condition (in which the virtual partner took 6 seconds to complete the captcha that consisted of 3 characters). The conditions were randomly mixed across rounds.

The experiment was preceded by three tutorials. The tutorials introduced the participants to the keypress task and the choice they would face on each round.

Data preparation and analysis. On each trial, we measured participants' choices between the less and more effortful option. This enabled us to calculate the proportion of choosing the more effortful option. We prepared and analyzed the data in rStudio (RStudio Team, 2016) using R 4.0.0 (R Core Team, 2020), the *rstatix* (v0.6.0; Alboukadel Kassambara, 2020), the *effsize* (v0.8.1; Torchiano, 2020), the *rjags* (v4-10; Martyn Plummer, 2019) and the *runjags* (v2.0.4-6; Matthew J. Denwood, 2016) packages.

For the Bayesian data analysis, we used a noncommittal broad prior on the parameters so that the prior had minimal influence on the posterior. We used Markov chain Monte Carlo (MCMC) techniques to generate representative credible values from the joint posterior distribution on the parameters (Kruschke, 2015). Three chains were initialized, well burned in (for 1,000 steps), and a total of 30,000 steps were saved. The chains were checked for convergence and autocorrelation and run long enough to produce an effective sample size (ESS) of at least 10,000 for all of the reported results. This yielded a stable and accurate representation of the posterior distribution on the parameters.

Results

To examine the effect of Perceived Effort on participants' effort investment, we followed the pre-registered analysis plan. Prior to conducting the analysis, we performed a Shapiro-Wilk test and it did not show evidence of non-normality ($W = 0.956$, $p = 0.182$). We conducted a paired-samples t-test, which revealed significant difference between conditions,

with participants choosing the more effortful option more in the High Perceived Effort condition ($M=0.616$, $SD=0.199$) than in the Low Perceived Effort condition ($M=0.528$, $SD=0.2$), ($t(33)=2.24$, $p=0.032$, *Cohen's d*= 0.44) (see **Figure 7**).

In addition to the pre-registered analysis plan, we also analyzed the data with Bayesian methods. We used a generalized linear mixed model, in which the predicted value is described as Bernoulli distributed around a linear combination of categorical predictors (Perceived Effort, random effect of participant and random slopes of condition nested within participant) mapped to a probability value via the logistic function. The results revealed a main effect of Perceived Effort. Accordingly, the credible values of the difference of High vs Low Perceived Effort had a mode of 0.418 and a 95% HDI that extended from 0.176 to 0.641; zero deemed not credible.

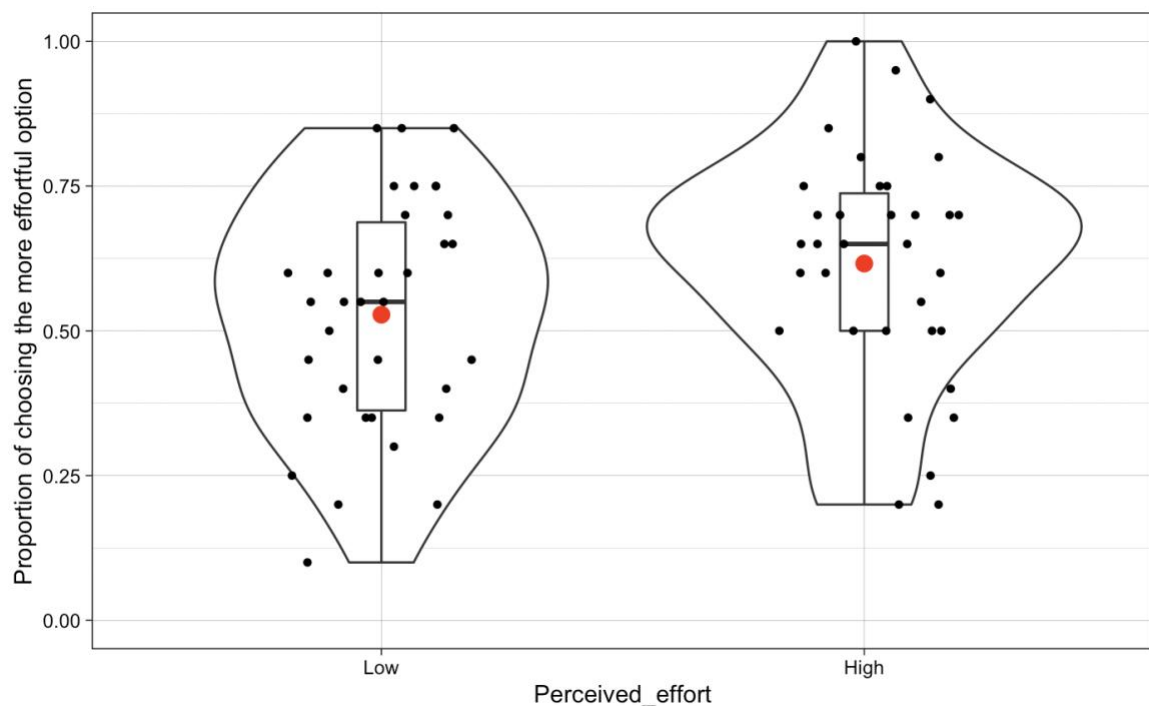


Figure 7. Proportion of choosing the more effortful option across conditions. Each black dot represents one participant's proportion of choosing the more effortful option in the respective condition. In each boxplot, horizontal lines indicate medians, and red circles indicate means.

Discussion

As predicted by the equity through effort calibration hypothesis, we found a main effect of Perceived Effort. Specifically, participants invested more effort in the High Perceived Effort condition than in the Low Perceived Effort condition, indicating a preference for fair distributions of effort costs. Insofar as this pattern would not be expected on the basis of the alternative idea that participants calibrate their effort investment simply out of a preference for acting jointly, these results provide clear support for the equity through effort calibration hypothesis.

It is also important to note that although there are other candidate explanations of why participants matched their partner's effort, we designed Experiment 2 in such a way as to control for them. To see this, consider three other candidate explanations for effort matching: environment-directed effort calibration, learning about the value of effort, and competition. As we discussed earlier, if one is uncertain about the reward structure of the environment, one may use others' investment of effort to infer the value of the activity, which in turn may lead one to increase or decrease one's effort investment as a function of the inferred reward value. However, in Experiment 2, participants always knew the reward value of their options on a given trial: the available reward values were the same and explicitly stated across all trials. Hence, this explanation does not predict effort matching in Experiment 2.

Another possibility is that by observing their partner's effort investments, participants learned about the value of effort and then made effort investments accordingly. However, this explanation would only be credible if observed effort investment had been rewarded (Leonard, Lee & Schulz, 2017; Eisenberger, 1992). Importantly, this was not the case in Experiment 2. Participants first observed their partners unlocking the round for high or low effort, and then they (participants) chose to invest high or low effort for joint rewards - i.e., participants did not observe their partners being rewarded for their effort investment.

Finally, another possibility is that participants may have competed with their partner. In general, participants may compete to win more points than a partner when their outcomes are independent or when they form a team and know that the jointly collected points will be evenly divided between them at the end. In the latter case, within-team competition could be an important strategy to boost performance. However, in Experiment 2, it was impossible for participants to compete or boost performance by competition. This is because their partner did not earn any points for the team, and their effort investment did not influence the available reward values subsequently. Instead, by unlocking the round, the partner made it possible for participants to choose between two reward options and so to earn points for the team.

In sum, although these candidate explanations may give rise to effort matching under certain circumstances, the results of Experiment 2 cannot be explained by them. Thus, the results of Experiment 2 provide clear support for the equity through effort calibration hypothesis.

General Discussion

A growing body of theoretical and empirical work suggests that our sense of fairness implies a preference for divisions of rewards that are proportional to contributions (André and Baumard, 2011; Baumard, André & Sperber, 2013; Debove, Baumard and André, 2015; Debove, Baumard and André, 2017; Frohlich, Oppenheimer and Kurki, 2004; Hamann, Bender and Tomasello, 2014; Kanngiesser and Warneken, 2012). This research has established that people are highly sensitive to the distribution of effort costs and that reward distribution is governed by a sense of fairness which takes effort investments into account. However, there has been no study testing whether people distribute effort costs according to the expected reward distribution. In the current study, we investigated the hypothesis that when people expect to share the reward of a joint task equally, they will ensure fairness by

calibrating their effort investment such as to reduce inequity with respect to joint action partners' effort investment (The equity through effort calibration hypothesis). Across two experiments, we tested this hypothesis and differentiated it from alternative explanations of why people match their partners' effort. In Experiment 1, we found partial support for the equity through effort calibration hypothesis, and we also found evidence for environment-directed effort calibration – i.e., participants used others' effort costs as information to infer the reward value of the environment, and this led them to increase or decrease their effort investment as a function of the inferred reward value. In Experiment 2, we found clear support for the equity through effort calibration hypothesis and were able to rule out other candidate explanations for the observed effort matching effect, such as a preference for acting jointly, learning the value of effort, and competition.

Our findings thus provide a valuable addition to existing research on the sense of fairness. To the best of our knowledge, this research provides the first evidence that the sense of fairness leads people not only to distribute resources according to individual effort costs but to distribute effort costs according to the expected reward distribution as well. This ability is important because in many contexts the success of joint action is uncertain and/or the outcome is not divisible. For example, hunting and foraging in ancestral environments were uncertain endeavors, and they may not have yielded any outcome to distribute at all. Similarly, the benefits of building a shelter or tidying up together may not produce any divisible outcome. In such instances, the only way to exhibit a sense of fairness is to invest effort equally.

The current findings also raise new questions for further research. For example: Do people prefer to ensure fairness by distributing outcomes according to individual effort costs or by distributing effort costs according to the expected outcome distribution? In our study,

and in previous work, participants could not choose freely between these options, so it is not currently possible to ascertain what people's preference would be given the choice. One possibility is that people prefer to rely on the fair distribution of outcomes. However, this seems to be the riskier choice insofar as a joint action may not yield any outcome at all. Therefore, we would speculate that people match their partner's effort even when there is an opportunity to distribute the outcomes afterwards. Moreover, people may match their partner's effort as a function of the expected probability of success of the joint action. Specifically, people may match their partner's effort more when the probability of success of the joint action is low, whereas they may match their partner's effort less when the probability of success of the joint action is high. Future work should investigate these predictions.

It is important to note that in our study we tested whether people distribute effort costs according to the expected outcome distribution by focusing on the special case of equally distributed outcomes. We did so because we thought that this type of case is characteristic of a great many real-world scenarios, such as putting up a tent or tidying up together, in which fairness cannot be ensured through the division of the outcome, and people are therefore especially motivated to distribute effort costs fairly. However, an important next step would be to test whether people distribute effort costs according to the expected outcome distribution by manipulating the expected outcome distribution. For example, we should expect that if people know that they will get $\frac{1}{3}$ of the joint outcome, then they should invest $\frac{1}{3}$ of the joint effort costs.

The results from Experiment 1 also show that people use others' investment of effort to infer the value of opportunities afforded by their environment, and that they adjust their effort accordingly. Findings from research on social learning show that people integrate

social information according to its reliability (De Martino, 2017; Boorman, 2013). Future research might further investigate the environment-directed effort calibration hypothesis by carefully manipulating the reliability of the partner's effort as a cue to the value of the task.

One limitation of the current research is that in both experiments we operationalized the partner's effort as the cognitive effort of deciphering a captcha, and participants' effort as the physical effort investment of repeated key presses. Future research should aim to generalize these findings by investigating whether other cues of a partner's cognitive or physical effort elicit effort matching on different effort measures.

In sum, the current research provides evidence that the sense of fairness should lead people not only to distribute resources according to individual effort costs but to distribute effort costs according to the expected reward distribution as well. These findings point to the unique human capacity to cooperate flexibly across a wide variety of contexts. Our findings not only shed new light on the psychological processes which serve to distribute the costs and benefits of joint actions, but also open up important new avenues of empirical and theoretical research on how people negotiate economies of effort in joint action.

Open practices

This project was pre-registered prior to data collection [Experiment 1: <http://aspredicted.org/blind.php?x=qw3t37> ; Experiment 2: <http://aspredicted.org/blind.php?x=7s5fc7>]. The reproducible scientific report (data and analysis code) is available in an online repository here [https://osf.io/ecszb/?view_only=cb443e65d0824e1c82f8bc20675d0951].

Chapter 5. Distributing Effort and Money in Dictator Games: Are Sharing Behaviors Resource-Specific?

As humans, we have unique skills and motivations for acting together (Tomasello et al., 2012; Sebanz, Bekkering & Knoblich, 2006; Nowak, 2006). Recent empirical research investigating these skills and motivations has begun focusing on how people negotiate economies of effort in joint action -- i.e. how they distribute effort among joint action partners. For example, Török, Pomiechowska, Csibra & Sebanz (2019) found that people minimized joint effort by either increasing their own or their partner's individual effort in joint action. Meanwhile, other studies (Székely & Michael, 2018; Chennells & Michael, 2018) have shown that people have a tendency to calibrate their effort level in joint actions to match that of their partners. Crucially, recent findings (Authors, under review) provide evidence that, in doing so, people are motivated by a preference for fair distributions of the costs and benefits of cooperation.

However, there remains an imbalance in the literature insofar as most research in distributive decisions has focused on how people distribute rewards, especially monetary ones. As a result, much is still unknown about the extent to which insights gained from research investigating how people distribute rewards can be generalized to scenarios in which people make decisions about how to distribute effort costs. For instance, the emerging pattern of results suggests that reputational considerations play an important role in people's decision-making with respect to the distribution of rewards – i.e., people are more willing to make fair choices in such contexts when their actions are observed by others and they desire to be recruited as partners in future cooperative interactions (Herrmann, Engelmann, & Tomasello, 2019; Engelmann, Over, Herrmann, & Tomasello, 2013; Barclay and Willer, 2007; Dana, Weber and Kuang, 2007). In one such study, Dana, Weber and Kuang (2007) contrasted four conditions in which participants took part in a dictator game with a binary choice between an equal and an unequal money allocation. The baseline condition was the

dictator's action and its effect was common knowledge as in other dictator games. In contrast, in the other three conditions, this transparency was relaxed by various methods: by allowing the dictator to remain ignorant about the effect of his action on the recipient, by introducing a second dictator, and by allowing the dictator to abdicate agency by letting the software make the decision. The results showed that eliminating transparency led to decreased giving in all three conditions (~35% of participants chose the fair option), relative to the baseline (74% of participants chose the fair option). The authors interpreted their findings as suggesting that while some people may value fairness, many others may value the *perception* of fairness. Furthermore, Engelmann, Over, Herrmann and Tomasello (2013) showed that even 5-year-old children strategically act to create an image as a fair person. Specifically, children chose to share 50% of their stickers with an absent, anonymous child when another child watching them could reciprocate later, compared with 35% when another child watching them could *not* reciprocate later. Taken together, these studies show that people are intrinsically motivated to value fair reward distributions (because they do so to some extent even when there is no reason to expect direct or indirect reciprocity), and that, over and above this, they are strategically motivated to value fair distributions in order to invest in potential direct or indirect reciprocity. Can these findings be generalized to scenarios in which people make decisions about how to distribute effort costs? In other words: are people motivated to create fair distributions of effort costs as a strategic investment in potential reciprocity? And to what extent are they motivated to do so even when there is no reason to expect reciprocity?

As it happens, we have reason to suspect that effort may engage intrinsic cooperative motivations even more powerfully than money. For example, Baumard, André and Sperber (2013) argue for an account of the evolution of fairness in which competition among cooperative partners leads people to strategically share the costs and rewards of cooperation equally. With time, however, this eventually leads to the selection of a disposition to be

intrinsically motivated to cooperate fairly. This is so because, at the psychological level, this may be a more cost-effective way of securing a good collaborative reputation than constantly engaging in the cost-benefit analyses of the implications of various sharing behaviors. If so, we should expect that the cost-effectiveness of strategic or intrinsic sharing behavior should depend on the resource type. In particular, we may expect higher levels of intrinsic sharing behaviour with respect to resources that are most prevalent in interactions. For example, cooperative interactions always involve effort costs but don't necessarily involve any distributable reward (e.g., collaborative ventures are sometimes unsuccessful, and the outcome is sometimes not divisible, such as when one is tidying up). If so, then scenarios requiring decisions about how to allocate effort may engage more robust intrinsic cooperative motivations. Specifically, while the need to allocate money may only weakly trigger an intrinsic motivation to cooperate fairly, the need to allocate effort may do so more strongly.

If we make comparisons across studies and populations, then existing experimental evidence suggests that there may be greater generosity in the context of effort costs than in the context of monetary rewards. In a labor allocation experiment, (Güth, 1984, as cited in Güth & Brandstätter, 1994, p. 166). asked pairs of participants to solve 12 tables of complex multiplication tasks for equal rewards. One member of each pair had the role of allocating the tables of multiplication tasks between them, and had a calculator, while their partner had to accept the task which was allocated to them and did not have a calculator. Only 5 of 62 participants allocated all the work to their partner, whereas the rest of participants tried to allocate the work in such a way that both them and their partner would end up investing equal work time (that is, allocators assigned to themselves around 9 to 12 tables of the 12 tables). This means that only 8.06% of all participants chose allocations that were maximally selfish. These results are in contrast with dictator games where the allocated resource is monetary. Engel (2011) conducted a meta-analysis on the results of 131 dictator games; he found that

on average 36.11% of all participants chose allocations that were maximally selfish - that is, they gave nothing to the recipient. Thus, this pattern of findings provides reason to suspect that there may be greater generosity in the context of effort costs than in the context of monetary rewards.

This line of reasoning motivates two hypotheses. First, we hypothesize that people may be strategically motivated to share effort fairly -- similarly to their strategic motivation to share money fairly (The resource-general hypothesis). If so, participants' decisions about resource allocation should depend on the expectations of reciprocity. We therefore predict that participants should share effort and money more fairly when there is an expectation of reciprocity. Second, we hypothesize that decisions about the allocation of effort may engage more intrinsic cooperative motivations than decisions about the allocation of money (The resource-specific hypothesis). This hypothesis leads to the prediction that participants should allocate effort more fairly than money, and changes in expectations of reciprocity should have a larger effect on participants' sharing behavior when the resource is money than when it is effort.

To test these hypotheses, we carried out four pre-registered experiments implementing a one-shot, anonymous dictator game. In the task, participants had to distribute resources (money or keypresses) between themselves and another player. They had to make this same choice 12 times, in 12 separate rounds, and they were told that at the end of the experiment, one round would be randomly selected, and that both players would be paid/have to perform keypresses accordingly.

In Experiment 1, we tested both hypotheses. To do so, we manipulated two factors in a between-subjects design. First, we manipulated the type of resource involved in the task: money or effort. Second, we manipulated participants' expectations of reciprocity: in the no

expectations of reciprocity condition, participants were told that the other player would never know whether the money they would get/the keypresses they would have to perform were determined by them or by the software; while in the low expectations of reciprocity condition, participants were told that the other player would know that they were the one deciding how to distribute the money/the effort; while in the high expectations of reciprocity condition, participants were told that the other player would know that they were the one deciding how to distribute the money/the effort and at some point in the experiment, the roles played by the participant and the other player might be reversed at any time. We predicted a main effect of resource type (The resource-specific hypothesis), i.e. that participants would share effort more fairly than money; a main effect of expectations of reciprocity (The resource-general hypothesis), i.e. that participants would share effort and money more fairly in the High expectations of reciprocity condition than in the Low and No expectations of reciprocity conditions, and that participants would share effort and money more fairly in the Low expectations of reciprocity condition than in the No expectations of reciprocity condition. We may also expect an interaction effect, i.e. that the effect of expectations of reciprocity would be larger in the Money condition than in the Effort condition (The resource-specific hypothesis).

To further test the domain-specific hypothesis, in addition to the manipulation of resource type (money or effort), we manipulated various factors in one-shot, anonymous dictator games that we hypothesized would differently influence the decision-making processes about money and effort, such as decision time, stake size, and perceived legitimacy. In this way, we drew upon established findings about resource allocation in the context of decision-making about monetary rewards, and we tested whether these findings could be extended to the context of decision-making about effort.

In Experiment 2, we drew upon previous work by Rand, Greene and Nowak (2012). They proposed that automatic, intuitive processes support cooperation in one-shot games because cooperative behaviours that are payoff-maximizing in a social environment governed by direct and indirect reciprocity spill over into one-shot anonymous interactions. In contrast, slow, controlled and deliberative processes favour behaviours that are payoff-maximizing in the current situation. Accordingly, a larger body of research (Rand et al., 2014; Evans and Rand; 2019) showed that people's choices are more cooperative under time pressure, when they are forced to reach their decision quickly (<10 s), than when they are forced to wait before responding (>10 s). We reasoned that if the resource-specific hypothesis is true, then the manipulation of decision time should have a larger effect on cooperativeness in the context of decision-making about money than in the context of decision-making about effort. This is so because we hypothesized that the intrinsic preference for fairness is more robust for effort than for money, and therefore deliberative processes would be less able to adjust intuitive responses in the context of decision-making about effort than in the context of decision-making about money. We therefore predicted that in the time pressure condition compared to the time delay condition, there would be a greater increase in cooperativeness in the money condition than in the effort condition.

In Experiment 3, we drew upon the stake size effect – i.e., multiple findings (Larney, Rotella and Barclay, 2019; Bechler, Green and Joel Myerson 2015; Engel, 2011) show that people are less generous when more money is at stake. Larney et al. (2019) explained this effect by suggesting that as the cost of giving increases, this results in increased selfishness. We reasoned that this increased cost of giving should influence people's decision-making processes in the context of decision-making about money than in the context of decision-making about effort because in the context of money, we expect participants to be more inclined to maximize expected utility and share resources strategically as result of a cost-

benefit analysis. In contrast, in the context of effort, we expect participants to show a more robust preference to share effort fairly under circumstances of changing utility. In contrast to the other experiments, we used the method of hypothetical payoffs (Kahneman & Tversky, 1979) so that we could use higher stakes without the constraints of our budget.

In Experiment 4, we drew upon previous work by Hoffman and Spitzer (1982,1985) and Hoffman, McCabe, Shachat & Smith (1994). In their experiments, they manipulated the perceived legitimacy of one participant being in a more advantageous position in an interaction such as a dictator or ultimatum game. They found that when participants had earned the more advantageous position (dictator, offerer) through their performance on a previous task, they behaved in a more self-regarding manner compared to when they had been allocated to the more advantageous position randomly – presumably because earning the advantageous position made them feel entitled to a greater reward. We reasoned that if the resource-specific hypothesis is true, then the manipulation of perceived legitimacy should have a larger effect on cooperativeness in the context of decision-making about money than in the context of decision-making about effort.

Experiment 1

Method

Participants. First, we collected data from 288 participants. Then, we analyzed the data with Bayesian parameter estimation, and we decided to double the precision in the estimate of parameters. We conducted a Bayesian power analysis suggesting that if we collect data from an additional 288 participants, we will double the precision in the estimate of parameters. Therefore, we collected data from 576 participants. Six individuals were excluded from analyses because they had less than 8 responses, leaving a sample of 570 (i.e. 570 participants: 247 female, $M_{age} = 25.80$ years, $SD_{age} = 7.61$ years) participants in the final dataset. All participants were recruited through the Prolific recruitment platform

(www.prolific.co), and they were naïve to the purpose of the study. All participants gave their informed consent at the start of the experiment, could withdraw from the experiment at any time, and received a small baseline fee of 35 pence for their participation in addition to the money they allocated to themselves in the experiment. The experiment was conducted in accordance with the Declaration of Helsinki and was approved by the United Ethical Review Board for Research in Psychology (EPKEB).

Apparatus and stimuli. The experimental task was written in JavaScript using PsychoJS and was hosted on Pavlovia.com. Participants were required to use a desktop computer to access the task. All experimental stimuli were defined relative to the height and width of the participant's screen.

Virtual waiting room: In order to create the impression that participants would be playing a multiplayer game with another participant, we had them wait in a virtual waiting room before the start of the experiment. They were informed that they were the first person out of two to sign up and that they would have to wait up to two minutes until another participant joined. While they were waiting, dots (height = 0.1) appeared and then disappeared sequentially.

Distribution task: Participants had a 10 second interval to indicate a point along a line (height=0.01, width=0.8) ranging from an allocation of 0% to the other participant (i.e. keeping 100% for themselves) to an allocation of 100% to the other participant (i.e. keeping 0% for themselves) by a mouse click (see **Figure 1**).

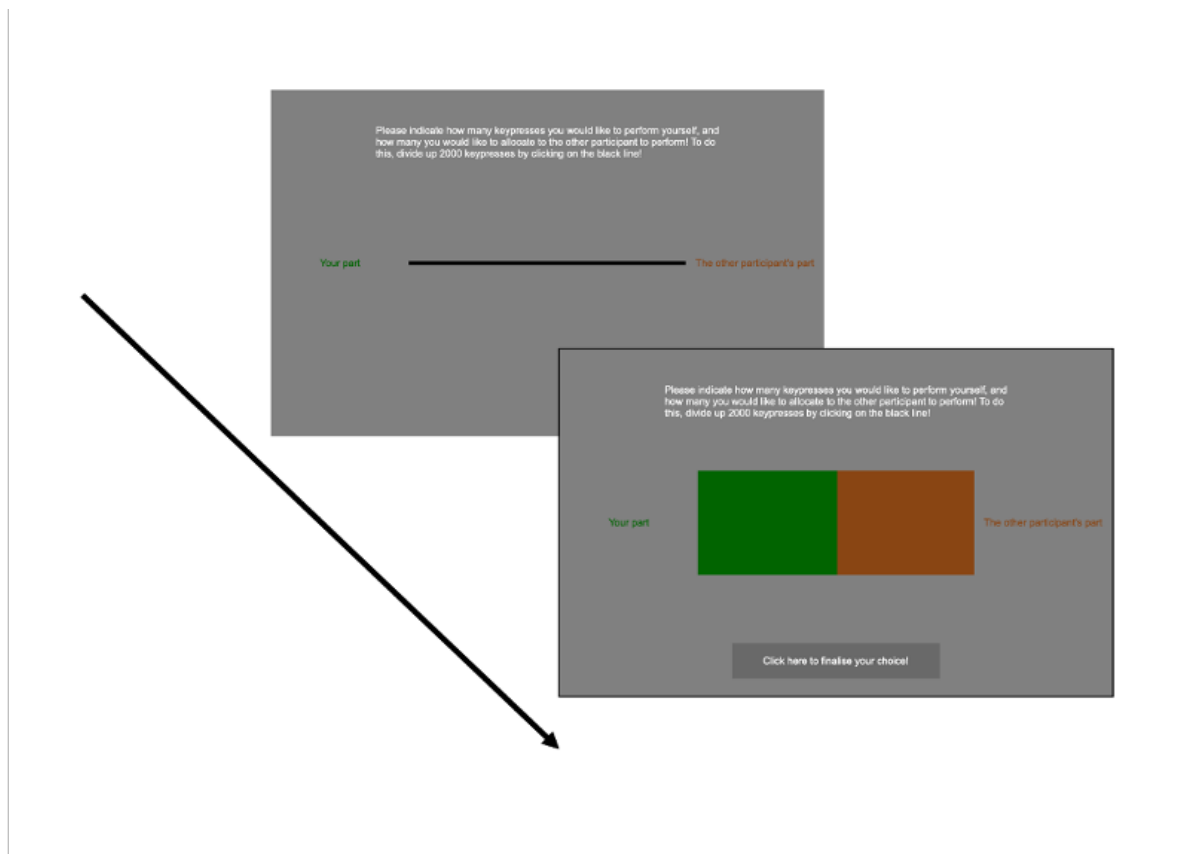


Figure 1: Distribution task. In each round, participants had to distribute keypresses/money between themselves and another participant.

Procedure. Participants were first informed that they were waiting for another participant to sign up for the study. This was done to lead participants to (falsely) believe that they were interacting with another participant in real-time. In reality, the other participant was in fact a virtual partner. We implemented this minor form of deception to implement our experiment efficiently on online platforms, while accommodating budget constraints. After waiting for around 1 minute, they were informed that another participant had signed up and that they were assigned to the role of Player A.

Then, participants were informed that they would be participating in a task in which they would have to distribute money/keypresses between themselves and another participant. They were informed that they would complete twelve rounds in total, and that one round

would be randomly selected and that they would be paid/have to perform keypresses accordingly. At the end of the experiment, participants were debriefed.

Design. In a between-subjects design, we manipulated two factors. First, we manipulated the type of resource involved in the task: money or effort. Second, we manipulated participants' expectations of reciprocity (no, low, and high): in the no expectations of reciprocity condition, participants were told that the other player would never know whether the money they would get/the keypresses they would have to perform were determined by them or by the software; while in the low expectations of reciprocity condition, participants were told that the other player would know that they were the one deciding how to distribute the money/the effort; while in the high expectations of reciprocity condition, participants were told that the other player would know that they were the one deciding how to distribute the money/the effort and at some point in the experiment, the roles played by the participant and the other player might be reversed at any time.

The dependent measure was participants' decisions about distributing resources. Specifically, in each group, on each trial, participants indicated a point along a line ranging from an allocation of 0% to the other participant (i.e. keeping 100% for themselves) to an allocation of 100% to the other participant (i.e. keeping 0% for themselves). In the effort groups, this means that they distributed 2000 keypresses between themselves and the partner; in the money groups, they distributed 1 pound.

Data preparation and analysis. On each trial, we measured participants' decisions about distributing resources. For participants in the money conditions, the self-favoring allocation score indicates the proportion of money they allocated to themselves; while for participants in the effort conditions, the self-favoring allocation score indicates the proportion of effort (i.e. keypresses) they allocated to their partner. We prepared and analyzed the data in rStudio (RStudio Team, 2016) using R 4.0.0 (R Core Team, 2020), the *tidyverse* (v1.3.0; Wickham

et al., (2019), the *rjags* (v4-10; Martyn Plummer, 2019) and the *runjags* (v2.0.4-6; Matthew J. Denwood, 2016) packages (see the reproducible report for more details).

Results

We were interested in predicting participants' decisions about distributing resources based on the six conditions. In the context of decision-making about money, participants allocated 53.80% of the money for themselves in the High expectations of reciprocity condition, 54.81% in the Low expectations of reciprocity condition and 59.41% in the No expectations of reciprocity condition. In the context of decision-making about effort, participants allocated 52.65% of the keypresses to the partner in the High expectations of reciprocity condition, 52.41% in the Low expectations of reciprocity condition and 53.64% in the No expectations of reciprocity condition (see **Figure 2**).

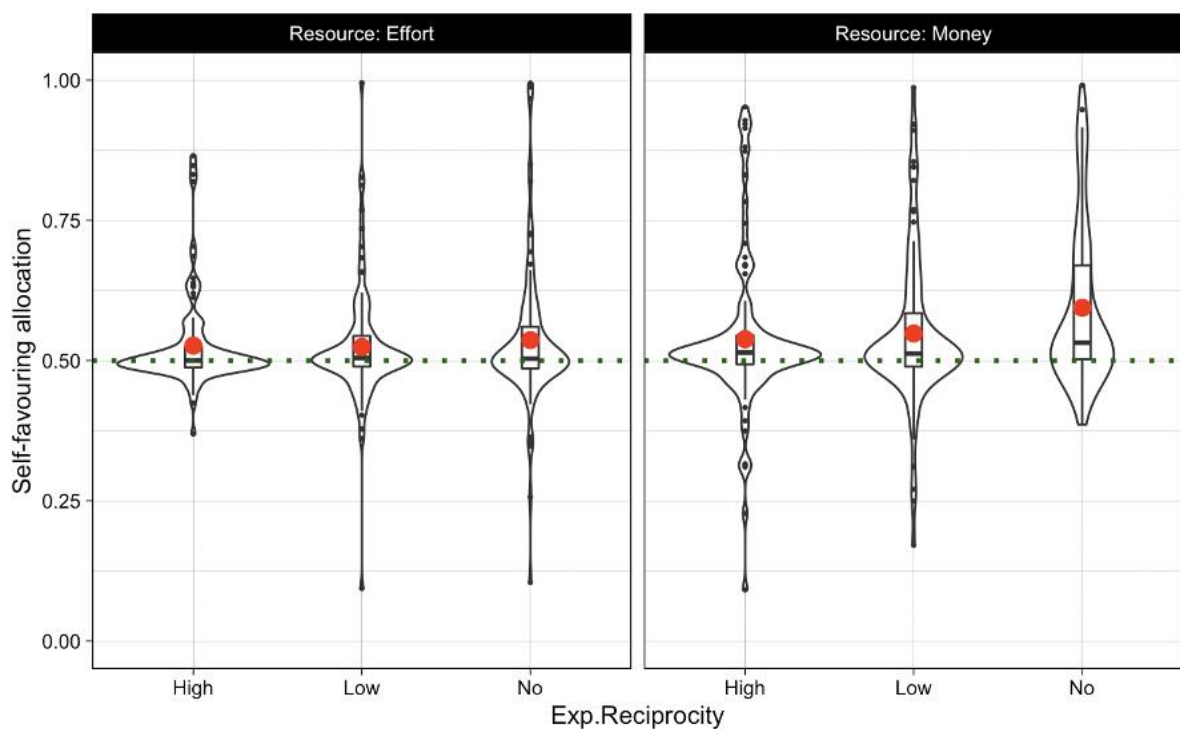


Figure 2: Self-favoring allocation score for each condition. For participants in the money conditions, the self-favoring allocation score indicates the proportion of money they allocated

to themselves; while for participants in the effort conditions, the self-favoring allocation score indicates the proportion of effort (i.e. keypresses) they allocated to the partner and *not* to themselves. The dotted green line indicates the fair allocation of resources. Each black dot represents an individual lying beyond 1.5 times the interquartile range. In each boxplot, horizontal lines indicate medians, and red circles indicate means.

We analyzed the data with Bayesian methods. We used a generalized linear distributional model, in which the predicted value is described as a beta distribution, parameterized as central tendency and dispersion. Accordingly, a linear combination of categorical predictors (Resource type, Expectations of reciprocity, Subjects) was mapped to the central tendency parameter via the logistic function, and a linear combination of categorical predictors (Resource type, Expectations of reciprocity, Subjects) was mapped to the dispersion parameter via the exponential function. We used a noncommittal broad prior on the parameters so that the prior had minimal influence on the posterior. We used Markov chain Monte Carlo (MCMC) techniques to generate representative credible values from the joint posterior distribution on the parameters (Kruschke, 2015). Three chains were initialized, well burned in (for 1,000 steps), and a total of 30,000 steps were saved. The chains were checked for convergence and autocorrelation and run long enough to produce an effective sample size (ESS) of at least 10,000 for all of the reported results. The posterior predictive check suggested that the model is a reasonable description of the data.

Central tendency. The results revealed a main effect of Resource type, a main effect of Expectations of reciprocity, and no interaction on the central tendency of participants' allocation decisions. Accordingly, the credible values of the difference of Resource type had a mode of -0.0828 and a 95% HDI that extended from -0.138 to -0.0278; zero deemed not credible. The credible values of the difference of High expectations of reciprocity and No

expectations of reciprocity had a mode of -0.0877 and a 95% HDI that extended from -0.146 to -0.0192; zero deemed not credible. The credible values of the difference of High expectations of reciprocity and Low expectations of reciprocity had a mode of -0.0251 and a 95% HDI that extended from -0.0955 to 0.0352; zero deemed credible. The credible values of the difference of Low expectations of reciprocity and No expectations of reciprocity had a mode of -0.0569 and a 95% HDI that extended from -0.124 to 0.0166; zero deemed credible. The credible values of the interaction effect had a mode of 0.107 and a 95% HDI that extended from -0.0144 to 0.244; zero deemed credible.

Dispersion. We used a distributional model that allowed us to estimate the differences of the central tendency and the dispersion of the response distributions simultaneously. The results revealed a main effect of Resource type, a main effect of Expectations of reciprocity, and no interaction on the dispersion of participants' allocation decisions. Accordingly, the credible values of the difference of Resource type had a mode of 0.75 and a 95% HDI that extended from 0.346 to 1.16; zero deemed not credible. The credible values of the difference of High expectations of reciprocity and No expectations of reciprocity had a mode of 0.835 and a 95% HDI that extended from 0.282 to 1.34; zero deemed not credible. The credible values of the difference of High expectations of reciprocity and Low expectations of reciprocity had a mode of 0.703 and a 95% HDI that extended from 0.185 to 1.27; zero deemed not credible. The credible values of the difference of Low expectations of reciprocity and No expectations of reciprocity had a mode of 0.176 and a 95% HDI that extended from -0.427 to 0.649; zero deemed credible. The credible values of the interaction effect had a mode of -0.175 and a 95% HDI that extended from -1.11 to 0.89; zero deemed credible.

Experiment 2

Method

Participants. Using G*power (Faul et al., 2009), we determined that a sample size of 192 would provide 90% power for detecting a medium-sized effect. Accordingly, we recruited 192 participants. Nine individuals were excluded from analyses because they had less than 8 responses, leaving a sample of 183 (i.e. 183 participants: 86 female, $M_{age} = 26.22$ years, $SD_{age} = 8.27$ years) participants in the final dataset. All participants were recruited through the Prolific recruitment platform (www.prolific.co), and they were naïve to the purpose of the study. All participants gave their informed consent at the start of the experiment, could withdraw from the experiment at any time, and received a small baseline fee of 35 pence for their participation in addition to the money they allocated to themselves in the experiment. The experiment was conducted in accordance with the Declaration of Helsinki and was approved by the United Ethical Review Board for Research in Psychology (EPKEB).

Apparatus and stimuli. The apparatus and stimuli were identical to that of Experiment 1.

Procedure. The procedure was identical to that of Experiment 1.

Design. In a between-subjects design, we manipulated two factors. We manipulated the type of resource: participants had to distribute either money or effort. Second, we manipulated Decision time: participants had to wait 2 seconds and then they had a 2-5 second interval to indicate their choices in the Time pressure condition, while they had to wait 5 seconds and then they had a 10 second interval to indicate their choices in the Time delay condition. The dependent measure was identical to that of Experiment 1.

Data preparation and analysis. The data preparation and analysis were identical to that of Experiment 1.

Results

We were interested in predicting participants' decisions about distributing resources based on the four conditions. In the context of decision-making about money, participants

allocated 53.71% of the money for themselves in the Time pressure condition and 52.09% in the Time delay condition. In the context of decision-making about effort, participants allocated 52.83% of the keypresses to the partner in the Time pressure condition and 55.02% in the Time delay condition (see **Figure 3**).

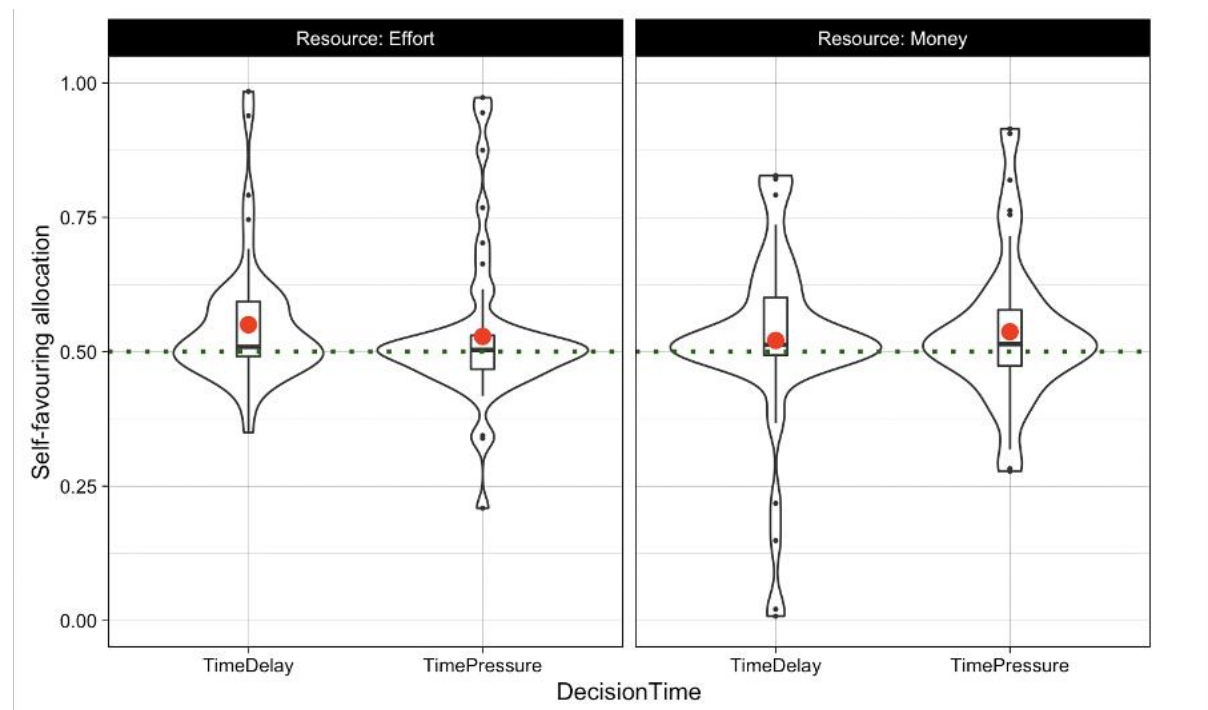


Figure 3: Self-favoring allocation score for each condition. For participants in the money conditions, the self-favoring allocation score indicates the proportion of money they allocated to themselves; while for participants in the effort conditions, the self-favoring allocation score indicates the proportion of effort (i.e. keypresses) they allocated to the partner and *not* to themselves. The dotted green line indicates the fair allocation of resources. Each black dot represents an individual lying beyond 1.5 times the interquartile range. In each boxplot, horizontal lines indicate medians, and red circles indicate means.

We analyzed the data with Bayesian methods. We used a generalized linear distributional model, in which the predicted value is described as a beta distribution, parameterized as central tendency and dispersion. Accordingly, a linear combination of categorical predictors (Resource type, Decision Time, Subjects) was mapped to the central

tendency parameter via the logistic function, and a linear combination of categorical predictors (Resource type, Decision Time, Subjects) was mapped to the dispersion parameter via the exponential function. We used a noncommittal broad prior on the parameters so that the prior had minimal influence on the posterior. We used Markov chain Monte Carlo (MCMC) techniques to generate representative credible values from the joint posterior distribution on the parameters (Kruschke, 2015). Three chains were initialized, well burned in (for 1,000 steps), and a total of 30,000 steps were saved. The chains were checked for convergence and autocorrelation and run long enough to produce an effective sample size (ESS) of at least 10,000 for all of the reported results. The posterior predictive check suggested that the model is a reasonable description of the data.

Central tendency. The results revealed no main effect of Resource type, no main effect of Decision time, and no interaction on the central tendency of participants' allocation decisions. Accordingly, the credible values of the difference of Resource type had a mode of 0.0172 and a 95% HDI that extended from -0.0848 to 0.139; zero deemed credible. The credible values of the difference of Decision Time had a mode of 0.0385 and a 95% HDI that extended from -0.0747 to 0.148; zero deemed credible. The credible values of the difference of differences had a mode of 0.00719 and a 95% HDI that extended from -0.0887 to 0.319; zero deemed credible.

Dispersion. The results revealed no main effect of Resource type, no main effect of Decision time, and no interaction on the dispersion of participants' allocation decisions. Accordingly, the credible values of the difference of Resource type had a mode of 0.0103 and a 95% HDI that extended from -0.61 to 0.618; zero deemed credible. The credible values of the difference of Decision time, had a mode of 0.0425 and a 95% HDI that extended from -

0.436 to 0.77; zero deemed credible. The credible values of the difference of differences had a mode of -0.0167 and a 95% HDI that extended from -1.33 to 0.598; zero deemed credible.

Experiment 3

Method

Participants. Using G*power (Faul et al., 2009), we determined that a sample size of 384 would provide 90% power for detecting a medium-sized effect. Accordingly, we recruited 384 participants. Two individuals were excluded from analyses because they did not finish the experiment, leaving a sample of 382 (i.e. 382 participants: 187 female, $M_{age} = 27.62$ years, $SD_{age} = 8.97$ years) participants in the final dataset. All participants were recruited through the Prolific recruitment platform (www.prolific.co), and they were naïve to the purpose of the study. All participants gave their informed consent at the start of the experiment, could withdraw from the experiment at any time, and received a small baseline fee of 38 pence for their participation in addition to the money they allocated to themselves in the experiment. The experiment was conducted in accordance with the Declaration of Helsinki and was approved by the United Ethical Review Board for Research in Psychology (EPKEB).

Apparatus and stimuli. The apparatus and stimuli were identical to that of Experiment 1.

Procedure. The procedure was identical to that of Experiment 1 except that we asked participants to make decisions about imagined scenarios and not about real resources.

Design. In a between-subjects design, we will manipulate two factors. First, we manipulated the type of resource involved in the task such as money or effort. Second, we manipulated the magnitude of the resource: 50, 300, 1800, 10800 keypresses or pounds. The dependent measure was participants' decisions about distributing resources. Specifically, for each group, participants will indicate a point along a line ranging from an allocation of 0% to the partner (i.e. keeping 100% for themselves) to an allocation of 100% to the partner (i.e. keeping 0%

for themselves). In the effort group, this means that they will distribute 50, 300, 1800, 10800 keypresses between themselves and the partner; in the money group, they will distribute 50, 300, 1800, 10800 pounds.

Data preparation and analysis. The data preparation and analysis were identical to that of Experiment 1.

Results

We were interested in predicting participants' decisions about distributing resources based on the eight conditions. In the context of decision-making about money, participants allocated 56.61%, 58.05%, 56.24%, 60.3% of the money for themselves in the 50, 300, 1800, 10800 pounds conditions. In the context of decision-making about effort, participants allocated 49.56%, 59.12%, 55.7%, 57.03% of the keypresses to the partner in the 50, 300, 1800, 10800 pounds conditions (see **Figure 4**).

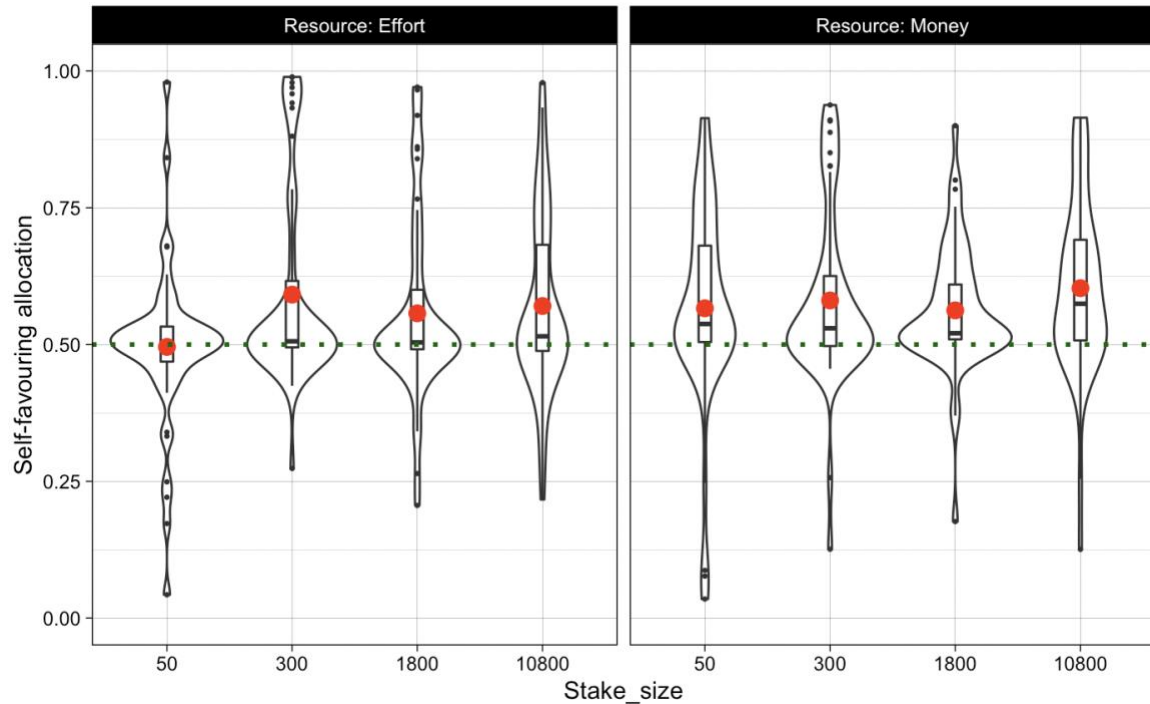


Figure 4: Self-favouring allocation score for each condition. For participants in the money conditions, the self-favouring allocation score indicates the proportion of money they allocated

to themselves; while for participants in the effort conditions, the self-favoring allocation score indicates the proportion of effort (i.e. keypresses) they allocated to the partner and *not* to themselves. Each black dot represents an individual lying beyond 1.5 times the interquartile range. In each boxplot, horizontal lines indicate medians, and red circles indicate means.

We analyzed the data with Bayesian methods. We used a generalized linear distributional model, in which the predicted value is described as a beta distribution, parameterized as central tendency and dispersion. Accordingly, a linear combination of categorical predictors (Resource type, Stake size, Subjects) was mapped to the central tendency parameter via the logistic function, and a linear combination of categorical predictors (Resource type, Stake size, Subjects) was mapped to the dispersion parameter via the exponential function. We used a noncommittal broad prior on the parameters so that the prior had minimal influence on the posterior. We used Markov chain Monte Carlo (MCMC) techniques to generate representative credible values from the joint posterior distribution on the parameters (Kruschke, 2015). Three chains were initialized, well burned in (for 1,000 steps), and a total of 30,000 steps were saved. The chains were checked for convergence and autocorrelation and run long enough to produce an effective sample size (ESS) of at least 10,000 for all of the reported results. The posterior predictive check suggested that the model is a reasonable description of the data.

Central tendency. The results revealed no main effect of Resource type, a main effect of Utility, and no interaction on the central tendency of participants' allocation decisions. Accordingly, the credible values of the difference of Resource type had a mode of 0.0342 and a 95% HDI that extended from -0.0871 to 0.217; zero deemed credible. The credible values of the difference of Utility had a mode of 0.121 and a 95% HDI that extended from 0.0244 to 0.415; zero deemed not credible. The credible values of the difference of

differences had a a mode of 0.311 and a 95% HDI that extended from -0.193 to 0.559; zero deemed credible.

Dispersion. The results revealed no main effect of Resource type, no main effect of Utility, and no interaction on the dispersion of participants' allocation decisions.

Accordingly, the credible values of the difference of Resource type had a mode of 0.151 and a 95% HDI that extended from -0.151 to 0.765; zero deemed credible. The credible values of the difference of Utility, had a mode of -0.00227 and a 95% HDI that extended from -0.537 to 0.499; zero deemed credible. The credible values of the difference of differences had a mode of -0.00454 and a 95% HDI that extended from -0.771 to 0.511; zero deemed credible.

Experiment 4

Method

Participants. Using G*power (Faul et al., 2009), we determined that a sample size of 192 would provide 90% power for detecting a medium-sized effect. Due technical reasons, we eventually recruited 199 participants. Three participants were excluded from analyses because they had less than 8 responses, leaving a sample of 196 (i.e. 196 participants: 111 female, $M_{\text{age}} = 26.55$ years, $SD_{\text{age}} = 7.30$ years) participants in the final dataset. All participants were recruited through the Prolific recruitment platform (www.prolific.co), and they were naïve to the purpose of the study. All participants gave their informed consent at the start of the experiment, could withdraw from the experiment at any time, and received a small baseline fee of 40 pence for their participation in addition to the money they allocated to themselves in the experiment. The experiment was conducted in accordance with the Declaration of Helsinki and was approved by the United Ethical Review Board for Research in Psychology (EPKEB).

Apparatus and stimuli. The apparatus and stimuli were identical to that of Experiment 1.

Procedure. The procedure was identical to that of Experiment 1 except that in the Earned position condition, participants were told that they and their part had to do a quiz and the winner earned the right to be Player A and started the experimental task from an advantaged position. On finishing the quiz, participants were told that they performed better than their virtual partner and therefore they would be the decision maker in the following task and Player B would have to accept their decisions.

Design. In a between-subjects design, we manipulated two factors. We manipulated the type of resource: participants had to distribute either money or effort. Second, we manipulated perceived legitimacy: participants had to win a quiz contest to earn the right to be the dictator in the Earned position condition, while they were randomly selected to be the dictator in the Random position condition. The dependent measure was identical to that of Experiment 1.

Data preparation and analysis. The data preparation and analysis were identical to that of Experiment 1.

Results

We were interested in predicting participants' decisions about distributing resources based on the four conditions. In the context of decision-making about money, participants allocated 61.76% of the money for themselves in the Earned position condition and 56.16% in the Random position condition. In the context of decision-making about effort, participants allocated 54.86% of the keypresses to the partner in the Earned position condition and

52.73% in the Random position condition (see **Figure 5**).

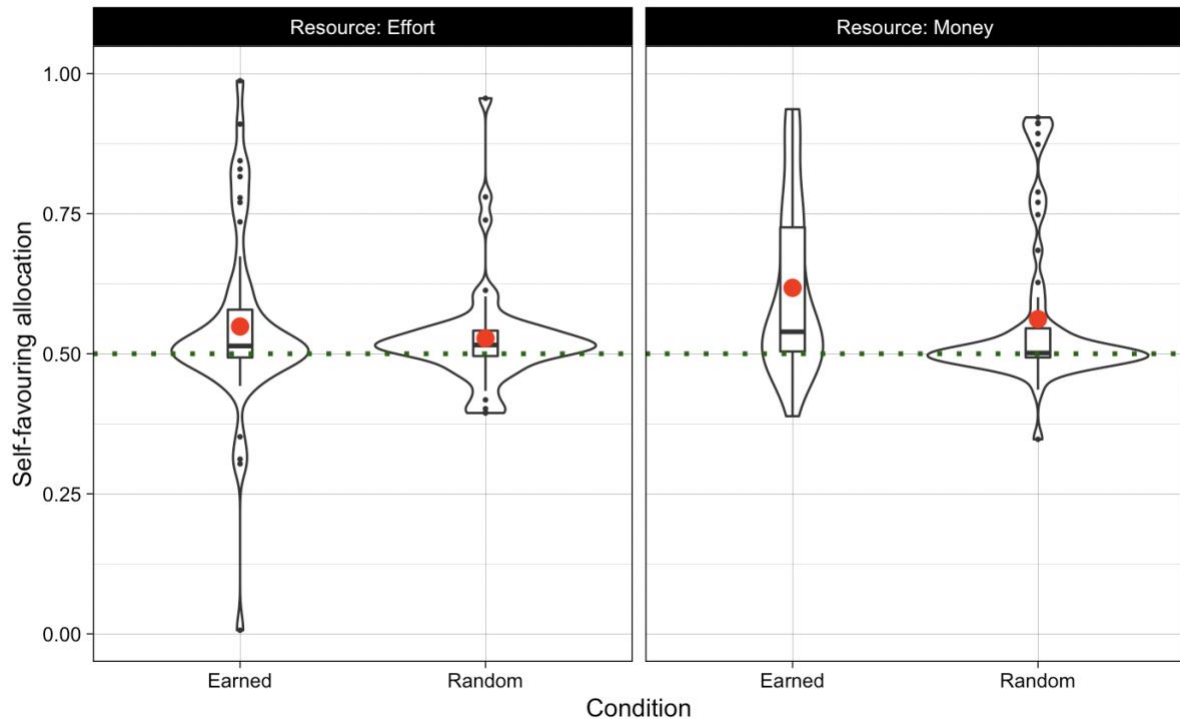


Figure 5: Self-favoring allocation score for each condition. For participants in the money conditions, the self-favoring allocation score indicates the proportion of money they allocated to themselves; while for participants in the effort conditions, the self-favoring allocation score indicates the proportion of effort (i.e. keypresses) they allocated to the partner and *not* to themselves. The dotted green line indicates the fair allocation of resources. Each black dot represents an individual lying beyond 1.5 times the interquartile range. In each boxplot, horizontal lines indicate medians, and red circles indicate means.

We analyzed the data with Bayesian methods. We used a generalized linear distributional model, in which the predicted value is described as a beta distribution, parameterized as central tendency and dispersion. Accordingly, a linear combination of categorical predictors (Resource type, Perceived legitimacy, Subjects) was mapped to the central tendency parameter via the logistic function, and a linear combination of categorical predictors (Resource type, Perceived legitimacy, Subjects) was mapped to the dispersion parameter via the exponential function. We used a noncommittal broad prior on the

parameters so that the prior had minimal influence on the posterior. We used Markov chain Monte Carlo (MCMC) techniques to generate representative credible values from the joint posterior distribution on the parameters (Kruschke, 2015). Three chains were initialized, well burned in (for 1,000 steps), and a total of 30,000 steps were saved. The chains were checked for convergence and autocorrelation and run long enough to produce an effective sample size (ESS) of at least 10,000 for all of the reported results. The posterior predictive check suggested that the model is a reasonable description of the data.

Central tendency. The results revealed no main effect of Resource type, a main effect of Perceived legitimacy, and no interaction on the central tendency of participants' allocation decisions. Accordingly, the credible values of the difference of Resource type had a mode of -0.0767 and a 95% HDI that extended from -0.228 to 0.0225; zero deemed not credible. The credible values of the difference of Perceived legitimacy had a mode of -0.171 and a 95% HDI that extended from -0.282 to -0.0235; zero deemed credible. The credible values of the difference of differences had a mode of 0.166 and a 95% HDI that extended from -0.202 to 0.338; zero deemed credible.

Dispersion. The results revealed no main effect of Resource type, no main effect of Perceived legitimacy, and no interaction on the dispersion of participants' allocation decisions. Accordingly, the credible values of the difference of Resource type had a mode of -0.0975 and a 95% HDI that extended from -0.797 to 0.406; zero deemed credible. The credible values of the difference of Perceived legitimacy, had a mode of 0.164 and a 95% HDI that extended from -0.356 to 0.936; zero deemed credible. The credible values of the difference of differences had a mode of -0.00684 and a 95% HDI that extended from -1.14 to 0.477; zero deemed credible.

General Discussion

Most research on distributive decision-making has focused on how people distribute rewards, especially monetary ones. For example, recent research has established that people are intrinsically motivated to value fair reward distributions (because they do so to some extent even when there is no reason to expect direct or indirect reciprocity), and that, over and above this, they are strategically motivated to value fair distributions in order to invest in potential direct or indirect reciprocity (Herrmann, Engelmann, & Tomasello, 2019; Engelmann, Over, Herrmann, & Tomasello, 2013; Barclay and Willer, 2007; Dana, Weber and Kuang, 2007). But due to the lack of research investigating people's distributive decision-making in the context of effort costs, we do not know to what extent these insights can be generalized to scenarios in which people make decisions about how to distribute effort. We believe that there is good reason to expect that they can indeed be generalised – namely, because effort costs would have been a centrally important resource in most cooperative interactions over the course of evolutionary history. As a result, any prosocial preferences supporting cooperation, such as a preference for fair distributions of resources, should be sensitive to effort costs. Thus, we hypothesized that they can be generalized to scenarios in which people make decisions about how to distribute effort costs. Specifically, we hypothesized that people are strategically motivated to share effort fairly, i.e., people should share effort more fairly when there is an expectation of reciprocity – similarly to their strategic motivation to share money more fairly when there is an expectation of reciprocity (The resource-general hypothesis). Moreover, because of the centrality of effort as a resource to be distributed in cooperative interactions, we also hypothesized that decisions about the allocation of effort are shaped by more robust intrinsic preference for fair distributions than decisions about the allocation of money (The resource-specific hypothesis).

In Experiment 1, we tested these hypotheses and we found support for the resource-general hypothesis. That is, the findings show that the effect of expected reciprocity in the

context of monetary rewards (Dana et al., 2007) generalizes to scenarios in which people make decisions about how to distribute effort costs. However, we found only partial support for the resource-specific hypothesis. This is because the main effect of Resource type is also consistent with an alternative explanation -- namely, that participants valued receiving money more than avoiding investing effort. In other words, the resources may have differed in their utility. To rule this out, we would have needed to observe an interaction effect between Resource type and Reciprocity. Specifically, we would have had to show that participants shared effort more fairly than money specifically in the No Reciprocity condition -- i.e., to a greater extent than in the Reciprocity conditions. And indeed, the analysis did reveal that an interaction effect was highly credible, with more than 95% of the probability density being above zero, and the magnitude of the interaction effect was in fact larger than the magnitude of the two main effects -- suggesting that people may have a higher intrinsic motivation to share effort fairly than money. However, the effect did not reach significance, so these results are not conclusive. Therefore, to further test the resource-specific hypothesis, we designed three more experiments.

To further test the resource-specific hypothesis, in addition to the manipulation of resource type (money or effort), we manipulated various factors that we hypothesized would differentially influence decision-making processes about money and effort. In Experiment 2, we drew upon previous work by Rand et al. (2012). They proposed that automatic, intuitive processes support cooperation in one-shot games because cooperative behaviors that are payoff-maximizing in a social environment governed by direct and indirect reciprocity spill over into one-shot anonymous interactions. In contrast, slow, controlled and deliberative processes favor behaviors that are payoff-maximizing in the current situation. Accordingly, a larger body of research (Rand et al., 2014; Evans & Rand, 2019) showed that people's choices are more cooperative under time pressure. We reasoned that if the intrinsic preference

for fairness is more robust for effort than for money, then deliberative processes would be less able to adjust intuitive responses in the context of decision-making about effort than in the context of decision-making about money. However, we found no effect of time pressure, no effect of resource type and no interaction. This does not provide support for the domain-specific hypothesis. The results are surprising in light of previous research showing that time pressure tends to increase participants' cooperativeness (Rand et al., 2012; Rand et al., 2014).

In Experiment 3, we drew upon the stake size effect – i.e., multiple findings (Larney et al., 2019; Bechler et al., 2015; Engel, 2011) show that people are less generous when more money is at stake. Larney et al. (2019) explained this effect by suggesting that as the cost of giving increases, this results in increased selfishness. We reasoned that this increased cost of giving should influence decision-making processes more in the context of money than in the context of effort because in the context of money, we expect participants to be more inclined to maximize expected utility and share resources strategically as a result of a cost-benefit analysis. In contrast, in the context of effort, we expect participants to show a more robust preference for fairness under circumstances of changing utility. We found an effect of stake size, no effect of resource type and no interaction. This does not provide support for the resource-specific hypothesis. One possible explanation for this null finding is the following: given that the sense of effort increases according to a power function (Hartmann et al., 2013), the marginal cost of generosity in the context of effort increases along with the stake size. Future research could investigate whether the utility function for increasing stake sizes may be different for effort and monetary rewards. Nevertheless, the results are consistent with previous research showing that people are less generous when more money is at stake (Larney et al., 2019; Bechler, et al., 2015; Engel, 2011). As such, these findings extend this so-called 'stake size effect' to the context of effort costs. It is important to note, however, that

in Experiment 3 we used hypothetical scenarios to investigate participants' sharing behavior with large stake sizes across the two contexts. Although there is evidence that people allocate monetary rewards similarly in real and hypothetical dictator games (Ben-Ner et al., 2008), this may not be true for effort, especially when the stake size increases.

In Experiment 4, we drew upon previous work by Hoffman & Spitzer (1982, 1985) and Hoffman et al. (1994). In their experiments, they manipulated the perceived legitimacy of one participant being in a more advantageous position in an interaction such as a dictator or ultimatum game. They found that when participants had earned the more advantageous position (dictator, offerer) through their performance on a previous task, they behaved in a more self-regarding manner compared to when they had been allocated to the more advantageous position randomly – presumably because earning the advantageous position made them feel entitled to a greater reward. We reasoned that if the intrinsic preference for fairness is more robust for effort than for money, then the manipulation of perceived legitimacy (whether they find themselves in the role of dictator because they earned it or because they were selected randomly) should have a larger effect on cooperativeness in the context of decision-making about money than in the context of decision-making about effort. We found an effect of perceived legitimacy, no effect of resource type and no interaction. This does not provide support for the resource-specific hypothesis. However, the results are consistent with previous research showing that increased perceived legitimacy tends to decrease participants' cooperativeness (Hoffman & Spitzer, 1982, 1985; Hoffman et al., 1994), and they extend the effect of legitimacy to the context of effort costs.

Taken together, our findings provide evidence for the hypothesis that the decision-making processes underlying people's distributive behaviour are resource-general in certain

respects, and no clear evidence for the hypothesis that they may be resource-specific in other ways as well. With respect to the former (i.e., the resource-general hypothesis), the results show that people share both effort and money more closely to an equal distribution in order to invest in potential direct or indirect reciprocity. With respect to the latter (i.e., the resource-specific hypothesis), however, do not provide support for this conjecture. However, the results show that participants' responses vary more in the context of decision making about money than in the context of decision making about effort. This may provide further motivation for the hypothesis, formulated above, that attitudes towards the distribution of effort are more basic and more robust than attitudes towards the distribution of money, and potentially less susceptible to cultural influence.

It is also important to acknowledge several limitations of the current research. One important limitation is that our findings might have been influenced by our choice of comparing the allocation of 2000 keypresses to the allocation of 1 pound in Experiment 1, 2 and 4. For example, in Experiment 1 the observed greater generosity in the domain of effort costs might have been due to the stake size being perceived as higher in the domain of monetary rewards. However, we believe that our choice was conservative – that is, to the extent that the stake size differed in the two domains, 2000 keypresses may count as a higher stake size than 1 pound. The reason for this is the following: when participants decided to take part in our experiments, they knew the baseline fee for their participation and the expected time needed to complete the task. In particular, our baseline fee was in line with the Prolific policy on minimum expected pay rate (which at the time was 0.11-0.13 pounds per minute). We decided to use this rate to determine the parity of the stakes in the two domains through the medium of time. This means that because 2000 keypresses require approximately 9 minutes to implement, 2000 keypresses in the domain of effort costs are equal to 1.05-1.20

pounds in the domain of monetary rewards (i.e., slightly more than the 1 pound with which we equated 2000 keypresses in the experiments).

Another limitation of the study is that in our experiments, allocation decisions can be seen as involving a loss (in the domain of effort costs) or gain (in the domain of monetary rewards) relative to the status quo. This is a potential confound because it has been shown that people are loss averse, i.e., people are more sensitive to losses than to gains of the same magnitude (Tversky & Kahneman, 1991). This means that similar allocations in terms of stake size may imply a greater change of utility in the domain of effort costs than in the domain of monetary rewards. Therefore, similar allocation behavior across the two domains may be underpinned by greater generosity in the domain of effort costs than in the domain of monetary rewards. As this difference in levels of generosity would not be captured by our experiments, the implementation of loss and gain frames may have worked against our hypothesis that participants would allocate effort costs more generously than monetary rewards. However, it is important to note that Davis et al. (2015) investigated the influence of loss and gain frames on people's level of generosity in the domain of time and in the domain of monetary rewards, and they found that people were more generous in the domain of time in both the loss and gain frames. Nevertheless, future research may assess the influence of the loss and gain frames on the domain of effort costs.

Another limitation of the study is that in all four experiments, participants' responses were very close to the equal distribution, making it difficult to detect differences among conditions and thereby to tease apart the cognitive and motivational mechanisms underpinning decisions about resource allocation. To address this in future research, it may be fruitful to devise experimental paradigms in which the pull of the selfish option is stronger.

A further limitation of the study is that in all four experiments, we operationalized participants' effort as the physical effort investment of repeated keypresses. In order to determine whether our findings generalize to other kinds of effort - e.g. cognitive effort - future research could investigate how people distribute effort on a range of effort tasks.

Conclusion

The current research provides evidence that people share both effort and money more closely to an equal distribution in order to invest in potential direct or indirect reciprocity. The current research also provided the first empirical test of the conjecture that people may have a more robust intrinsic motivation to share effort fairly than money. While our results provide some initial evidence for this hypothesis, the overall pattern of findings did not support it.

Open practices

The experiments were pre-registered prior to data collection [Experiment 1: https://osf.io/wd6q2/?view_only=750f88d7a7124bbca84534ba483ac2b0; Experiment 2: https://osf.io/8g2a3/?view_only=2662e081239b4877aabc94bee1c73ab8; Experiment 3: https://osf.io/pt7dk/?view_only=a4b1e34112134400bb0c3206f9de9819; Experiment 4: https://osf.io/cd23q/?view_only=fd86cbceb37747a6a133b1e472fe8dc1]. The reproducible scientific reports (data and analysis code) are available in an online repository here [https://osf.io/xqdfg/?view_only=9d1396926b084e98a017a437e0f15b09].

Chapter 6. General Discussion

In this dissertation, I investigated why people match their joint action partner's effort. In particular, I aimed to illuminate why evolution would have equipped us with such a tendency, and what the proximate psychological mechanisms underpinning it may be. In theorizing about the potential functions of effort matching, I started from the observation that agents may respond to others' effort in order to optimize their effort investment to the relationship with the other agent (*relationship-directed effort calibration*), to the environment (*environment-directed effort calibration*) or to some combination of the two.

With respect to the former (relationship-directed effort calibration), I drew upon previous work on partner choice models of mutualistic cooperation (Barclay, 2013; Barclay & Willer, 2007; Gurven, 2004; Noë & Hammerstein, 1994, 1995), which suggests that when individuals can choose partners, there is selection pressure favoring psychological adaptations for choosing, attracting and maintaining good collaboration partners. Crucially, this research has established that people's decision-making processes with regard to the distribution of rewards reflect the ultimate goal of attracting and retaining good collaboration partners. Extending these results, I argued that the psychological mechanisms that guide people's investment of effort in collaborative ventures are likely to have been under similar selection pressure as the psychological mechanisms that guide the distribution of rewards. Accordingly, I hypothesized that people may calibrate their effort investment in joint action with the ultimate goal of attracting and retaining good collaboration partners, and as a consequence, we should expect that this is reflected at the level of proximate psychological mechanisms that determine how people allocate effort (*The relationship-directed effort calibration hypothesis*).

With respect to the latter (environment-directed effort calibration), I drew upon two distinct strands of research: work on social referencing going back several decades, and more

recent research on the naïve utility calculus. Decades of work on social referencing have shown that people routinely use others' facial expressions, postures and actions as a source of information to determine which course of action is most worth pursuing (Leonard et al., 2017; Egyed et al., 2013; Parkinson et al., 2012; Sorce et al., 1985; Darley & Latané, 1968). In addition, recent theoretical and empirical work on the naïve utility calculus suggests that people competently make a vast array of inferences even at the age of 10 months by building on the assumption that other agents act to maximize subjective utility (Baker et al., 2017; Jara-Ettinger, Gweon, Schulz & Tenenbaum, 2016; Jara-Ettinger, Gweon, Tenenbaum & Schulz, 2015; Liu et al., 2017). Drawing on these results, I argued that people may use their partner's effort costs as information to infer the value of opportunities afforded by their environment, which may lead them to adjust their effort investment to obtain maximal reward for minimal effort costs (*The environment-directed effort calibration hypothesis*).

Across Chapters 2-5, I presented a range of empirical studies that bear upon these hypotheses, distinguished them theoretically and empirically from a range of alternative hypotheses, and situated the results in the context of previous research. The first step (Chapter 2) was to address a prerequisite condition. In particular, in order to calibrate our efforts to that of others, we need to be able to perceive others' effort - i.e. we need to have the capacity to estimate the effort costs that observed agents are currently investing in specific ongoing activities. Therefore, in Chapter 2, I identified some of the relevant factors that feed into adults' judgments about the level of others' effort. Then in Chapters 3-4, I investigated a battery of hypotheses about the evolutionary functions which may explain why people match their partner's effort, as well as a battery of hypotheses about the proximate psychological mechanisms underpinning this behavior. Finally, in Chapter 5, I examined the extent to which insights gained from research investigating how people distribute rewards (typically monetary rewards) can be generalized to scenarios in which people make decisions about

how to distribute effort costs. In the following, I summarize the findings of these four empirical studies and discuss their theoretical implications, as well as the questions they raise for future research.

Perceiving Others' Effort Costs (Chapter 2)

In Chapter 2, I tested whether adults estimate others' cognitive effort costs by tracking perceptible properties of movement such as path length, speed or time. I hypothesized that because greater magnitude in path length, speed or time typically corresponds to greater outlays of energy, people expect the magnitude of these cues to be correlated with effort costs. In the task, participants viewed videos in which stars progressively appeared to indicate that a partner was solving a captcha, and then they were asked how much effort they thought it had taken the partner to solve this captcha. Participants estimated others' effort costs of deciphering a captcha on a Likert scale (1-7). Across two experiments, I found that - although participants rated more steps (captchas consisting of more characters) as more effortful than less steps and they rated slower action as more effortful than faster action - only time had a consistent effect on effort perception, i.e., participants rated longer time as more effortful than shorter time. Taken together, the results suggest that within the context of the present task - observing an agent deciphering a captcha - people rely on the time of others' action to estimate others' cognitive effort costs.

The findings expand upon previous research in several ways. First, they provide a crucial test of assumptions about effort perception made by a large body of work using movement cues as a basis for effort perception. In addition, I tested whether the principles gained from experiments implementing physical effort costs can be extended to situations in which adults have the task to perceive *cognitive effort* through movement cues. To my knowledge, the experiments reported here are the first to directly test how adults perceive others' cognitive effort costs. These findings reinforce the view (Runeson et al., 1981;

Runeson et al., 1983) that visual kinematic patterns are readily used by humans to specify the influence of animal-dynamic properties such as intention, expectation, and effort.

Future Research

In the study, I focused on the systematic differences in how people rate others' cognitive effort costs in deciphering a captcha. However, this study did not speak to the accuracy of these ratings. An interesting next step would be to test this by correlating participants' ratings of others' effort costs with those other agents' own internal assessment of their effort investment.

Our findings provide support for the hypothesis that people perceive others' effort costs by tracking perceptible properties of movement. However, there are at least two other hypotheses about the sources of information and mechanisms operating on them that may enable us to perceive others' effort. First, building on results suggesting that during observation of an action, a corresponding representation in the observer's cortical motor system is activated (Rizzolatti and Craighero, 2004; Frith & Singer, 2008), it may be fruitful to explore the possibility that we perceive others' effort through our own motor system. Second, one may speculate that we estimate effort costs by tracking perceptible properties of others' autonomic nervous systems such as breathing patterns and cues of muscle tension, because cues to the level of activity of the autonomic nervous system convey information about the current level of effort investment (Rejeski & Lowe, 1980; de Morree & Marcora, 2010). Critically, these mechanisms of effort perception are mutually compatible and may or may not interact in a number of different ways. Further research is needed to distinguish among these hypotheses and to clarify how we integrate these various sources of information.

Functions and Mechanisms of Effort Matching (Chapter 3 and 4)

In chapters 3 and 4, I turned my attention to the main theoretical issue at the heart of the dissertation – namely, to investigate whether people may match others' effort to optimize their effort investment to the relationship with others (*relationship-directed effort calibration*), to the environment (*environment-directed effort calibration*) or to some combination of the two. The chapters address this issue from two complementary perspectives: chapter 3 focuses on decision-making processes during the course of ongoing action, while chapter 4 focuses on decision-making processes preceding action.

Chapter 3: Effort-Based Decision Making in Joint Action: Evidence of a Sense of Fairness

In Chapter 3, I presented three experiments which investigated the relationship-directed effort calibration hypothesis and the environment-directed effort calibration hypothesis, and distinguished them from alternatives. In carrying out these experiments, I designed and implemented a task in which participants had to repeatedly press a button to reach a target in order to obtain an unknown reward (1 or 5 points). Critically, the target was invisible and participants had to decide how long to persist before quitting. Before their turn, they observed as their partner performed the same task. Importantly, at the beginning of the trial, the reward value was only revealed to their partners. By manipulating the perceived effort of their partner, and participants' beliefs about the reward structure of the task (whether the reward structure of the task was the same/opposite for them and their partner, or whether it was uncertain), I was able to investigate how participants used the perception of their partner's effort investment in their decision-making about how much effort to invest.

In Experiments 1 and 2, I differentiated the relationship-directed effort calibration hypothesis from the hypothesis that people may use their partner's effort costs as information to infer the value of opportunities afforded by their environment, which may lead them to

adjust their effort investment as a function of the inferred value (The *environment-directed effort calibration hypothesis*). In Experiment 1, I found support for the relationship-directed calibration hypothesis in one subgroup and we found support for the environment-directed effort calibration hypothesis in a distinct subgroup. However, with respect to each of these subgroups, there is an alternative explanation which I was not able to rule out: namely, that participants within the different subsets exhibited the observed patterns in order to appear competent (The *appearance of competence hypothesis*). Experiment 2 was designed to rule this out as an alternative explanation of the subgroup that exhibited environment-directed effort calibration – i.e., this subgroup of participants may have inferred that their partner was aware that the reward structures were incongruent in the Incongruent condition, and may accordingly have invested greater effort in the Low Partner Effort condition and less effort in the High Partner Effort condition in order to demonstrate competence and efficiency to their partner. To address this, in Experiment 2, participants were informed that their partner always believed that they were in a congruent reward structure, and we found clear support for both the relationship-directed and the environment-directed effort calibration hypotheses.

Having found evidence for the relationship-directed effort calibration hypothesis in Experiments 1 and 2, I next turned my attention to the proximal psychological motives underpinning these effects, and specifically to testing the hypothesis that when people expect to share the reward of the joint task equally, people ensure fairness by calibrating their effort investment such as to reduce inequity with respect to joint action partners' effort investment (The *equity through effort calibration hypothesis*). Experiments 1 and 2 do not directly support this hypothesis because they were not designed to rule out the appearance of competence hypothesis. To address this, Experiment 3 provided evidence of relationship-directed effort calibration, but in a context in which it could uniquely be explained by the

equity through effort calibration hypothesis – i.e., in which the appearance of competence hypothesis could be ruled out.

This research offers the first evidence for functional explanations of why people match their joint action partner's effort, and thereby provide a valuable contribution to attaining a fuller understanding of the role of effort and effort perception in human cooperative interactions. First, the findings demonstrate that people calibrate their effort investment in joint action with the ultimate goal of attracting and keeping good collaboration partners and that the proximal psychological motive that drive them to do so is a preference for fairness. The findings reinforce the view that people's decision-making processes about the distribution of costs and benefits of cooperation should reflect the ultimate goal of attracting and keeping good collaboration partners (Barclay, 2013; Baumard et al., 2013; Debove et al., 2015; Debove et al., 2017). Second, the findings show that people use others' investment of effort to infer the value of opportunities afforded by their environment, and that they adjust their effort accordingly. These findings are consistent with a large body of work on naïve utility calculus suggesting that human beings from early infancy assume that other agents act to maximize subjective utility (Jara-Ettinger, Gweon, Tenenbaum & Schulz, 2016).

Future Research

These findings relate to previous research on how people prioritize overall efficiency over a consideration of fairness. Strachan & Török (2020) found evidence that in joint action people prioritize joint efficiency over fairness. However, in their experiments the effort costs were small for participants, and the authors identified the possibility that fairness may affect decision-making more when there are substantial action costs. The current research supports this conjecture by demonstrating that when the costs are higher, some participants are more strongly motivated by fairness than by efficiency considerations. Moreover, by identifying

distinct subgroups that are more strongly motivated by the one than the other, they raise the intriguing possibility that there may be substantial individual differences with respect to the relative strength of these motives. Further research is needed in order to catalog and to explain these individual differences.

Chapter 4: In It Together: Evidence of a Preference for the Fair Distribution of Effort in Joint Action

In Chapter 4, I further investigated why people match their joint action partner's effort. I hypothesized that when people expect to share the reward of the joint task equally, they ensure fairness by calibrating their effort investment such as to reduce inequity with respect to joint action partners' effort investment (The equity through effort calibration hypothesis). To this end, I developed a task in which participants observed as their partner performed a cognitive effort task, and then they traded off physical effort costs against reward. I manipulated whether the reward structure was joint or separate, and whether the available reward was known or unknown. This enabled me to create scenarios in which I could test the aforementioned hypothesis and differentiate it from alternative explanations. In Experiment 1, I found partial support for the equity through effort calibration hypothesis, and I found evidence for environment-directed effort calibration – i.e., participants used others' effort costs as information to infer the reward value of the environment, and this led them to increase or decrease their effort investment as a function of the inferred reward value. In Experiment 2, I found clear support for the equity through effort calibration hypothesis and I was able to rule out other candidate explanations for the observed effort matching effect, such as a preference for acting jointly, learning the value of effort, and competition.

The findings provided further evidence for the relationship-directed effort calibration hypothesis and the environment-directed effort calibration hypothesis. In addition, Chapter 4 extended the investigation of the functions and mechanisms of effort matching in two

important ways. First, in Chapter 4, participants and their partner contributed *different kinds of effort in different ways* (the partner's effort was operationalized as the cognitive effort of deciphering a captcha, and participants' effort was operationalized as the physical effort investment of repeated key presses). This is in contrast to the experiments presented in Chapter 3, where participants and their partner contributed *the same kind of effort in the same way* (both the partner's effort and participants' effort were operationalized as the physical effort investment of repeated key presses). This enabled me to generalize the findings of Chapter 3 by showing that participants are able to compare different kinds of effort and to adjust to their partner's effort accordingly. Second, the decision-making processes underpinning the exertion of effort relate to different phases of behaviour: first, one must decide whether one is willing to exert the anticipated effort costs ("Is it worth it?"); then, during the course of the action, there is an ongoing need to determine to what extent one's action should be energized in order to achieve the desired results ("Should I persist?") (Heron, Apps, Husain; 2018). While in Chapter 3 we measured participants' willingness to invest effort in the process of investing effort, i.e., in the phase of "Should I persist?"; in Chapter 4 we measured participants' willingness to invest effort when they decided whether they were willing to exert the anticipated effort costs, i.e., in the phase of "Is it worth it?". This enabled me to generalize the findings of Chapter 3 by showing that participants calibrate their own effort investment in the direction of that of a joint action partner in both phases of behavior.

Taken together, the findings presented in chapters 3 and 4 provide a valuable addition to existing research on the sense of fairness. In particular, they provide the first evidence that the sense of fairness leads people not only to distribute resources according to individual effort costs but to distribute effort costs according to the expected reward distribution as well. This ability is important because in many contexts the success of joint action is uncertain

and/or the outcome is not divisible. For example, co-parenting or tidying up together may not produce any divisible outcome. In such instances, the only way to exhibit a sense of fairness is to invest effort equally.

Future Research

Chapter 4 expanded on the findings of Chapter 3 by showing that participants are able to compare different kinds of effort and adjust to their partner's effort accordingly. However, there has not been much research on inter-individual effort comparison in joint action, and so it is not clear how precisely people *can* match their partner's level of effort even if they want to do so (cf. Liang, Wolf, Török, Székely, Michael, 2019). Further research is needed to address this question.

It is important to note that in Chapter 4 I tested whether people distribute effort costs according to the expected outcome distribution by focusing on the special case of equally distributed outcomes. I did so because I thought that this type of case is characteristic of a great many real-world scenarios, such as co-parenting or tidying up together, in which fairness cannot be ensured through the division of the outcome, and in which a preference for distributing effort costs should therefore play a particularly essential role in decision making. However, an important next step would be to test whether people distribute effort costs according to the expected outcome distribution by manipulating the expected outcome distribution. For example, we should expect that if people know that they will get $\frac{1}{3}$ of the joint outcome, then they should invest $\frac{1}{3}$ of the joint effort costs.

The findings also raise new questions about how people distribute the costs and benefits of cooperation. Do people prefer to ensure fairness by distributing reward according to individual effort costs or by distributing effort costs according to the expected reward distribution? In Chapter 4, and in previous work, participants could not choose freely

between these options, so it is not currently possible to ascertain what people's preference would be given the choice. One possibility is that people prefer to rely on the fair distribution of reward. However, this seems to be the riskier choice insofar as a joint action may not yield any reward at all. Therefore, I would speculate that people match their partner's effort even when there is an opportunity to distribute the outcomes afterwards. Moreover, people may match their partner's effort as a function of the expected probability of success of the joint action. Specifically, people may match their partner's effort more when the probability of success of the joint action is low, whereas they may match their partner's effort less when the probability of success of the joint action is high. Future work should investigate these predictions.

Distributing costs and benefits: Are Sharing Behaviors Resource-Specific? (Chapter 5)

In Chapter 5, I examined the extent to which insights gained from research investigating how people distribute monetary rewards can be generalized to scenarios in which people make decisions about how to distribute effort costs. This is important insofar as it provides a crucial test of a (very reasonable and pragmatic assumption) made by most research in behavioral economics and psychological game theory -- although most research homes in on money as the critical resource to be gained, lost, and distributed, the aim in doing so is to illuminate how people make decisions with regard to gaining, losing, and distributing resources more generally. And indeed, effort is a highly ubiquitous and important resource in everyday life at present, as it has been throughout evolutionary history. Thus, if insights gained from research using monetary rewards can successfully be extended to contexts involving effort, it would provide a powerful vindication of previous research in behavioral economics and psychological game theory, and by the same token demonstrate how joint action research can benefit from the insights, constraints and methods from these complementary strands of research on decision-making.

I hypothesized that people are strategically motivated to share effort fairly, i.e., I predicted that people would share effort more fairly when there is an expectation of reciprocity – similarly to their strategic motivation to share money more fairly when there is an expectation of reciprocity. In addition, I also hypothesized that decisions about the allocation of effort are shaped by more robust intrinsic preference for fair distributions than decisions about the allocation of money. I reasoned that effort costs would have been a crucial resource to be distributed in most cooperative interactions throughout our evolutionary history (more so than money), so the cost-effectiveness of an intrinsic preference for equal distributions with respect to effort should be even more pronounced than the cost-effectiveness of an intrinsic preference for equal distributions of money, and accordingly the preference for fair distributions of effort should be even more robust than the preference for fair distributions of money. In Experiment 1, I tested these hypotheses online, using a one-shot, anonymous dictator game. By manipulating resource type and expectation of reciprocity, I created scenarios in which I could compare and contrast how people distribute effort costs and rewards between themselves and another player. The results provide support for the resource-general hypothesis, but only partial support for the resource-specific hypothesis. Therefore, to further test the resource-specific hypothesis, I designed three more experiments.

In Experiment 2, I drew upon previous work by Rand et al. (2012). They proposed that automatic, intuitive processes support cooperation in one-shot games because cooperative behaviors that are payoff-maximizing in a social environment governed by direct and indirect reciprocity spill over into one-shot anonymous interactions. In contrast, slow, controlled and deliberative processes favor behaviors that are payoff-maximizing in the current situation. Accordingly, a larger body of research (Rand et al., 2014; Evans & Rand; 2019) showed that people's choices are more cooperative under time pressure. I reasoned that

if the intrinsic preference for fairness is more robust for effort than for money, then deliberative processes would be less able to adjust intuitive responses in the context of decision-making about effort than in the context of decision-making about money. However, I found no effect of time pressure, no effect of resource type and no interaction. This does not provide support for the domain-specific hypothesis. The results are surprising in light of previous research showing that time pressure tends to increase participants' cooperativeness (Rand et al., 2012; Rand et al., 2014).

In Experiment 3, I drew upon the stake size effect – i.e., multiple findings (Larney et al., 2019; Bechler et al., 2015; Engel, 2011) show that people are less generous when more money is at stake. Larney et al. (2019) explained this effect by suggesting that as the cost of giving increases, this results in increased selfishness. I reasoned that this increased cost of giving should influence decision-making processes more in the context of money than in the context of effort because in the context of money, I expect participants to be more inclined to maximize expected utility and share resources strategically as a result of a cost-benefit analysis. In contrast, in the context of effort, I expect participants to show a more robust preference for fairness under circumstances of changing utility. I found an effect of stake size, no effect of resource type and no interaction. This does not provide support for the resource-specific hypothesis. One possible explanation for this null finding is the following: given that the sense of effort increases according to a power function (Hartmann et al., 2013), the marginal cost of generosity in the context of effort increases along with the stake size. Future research could investigate whether the utility function for increasing stake sizes may be different for effort and monetary rewards. Nevertheless, the results are consistent with previous research showing that people are less generous when more money is at stake (Larney et al., 2019; Bechler, et al., 2015; Engel, 2011). As such, these findings extend this so-called 'stake size effect' to the context of effort costs. It is important to note, however, that

in Experiment 3 I used hypothetical scenarios to investigate participants' sharing behavior with large stake sizes across the two contexts. Although there is evidence that people allocate monetary rewards similarly in real and hypothetical dictator games (Ben-Ner et al., 2008), this may not be true for effort, especially when the stake size increases.

In Experiment 4, I drew upon previous work by Hoffman & Spitzer (1982, 1985) and Hoffman et al. (1994). In their experiments, they manipulated the perceived legitimacy of one participant being in a more advantageous position in an interaction such as a dictator or ultimatum game. They found that when participants had earned the more advantageous position (dictator, offerer) through their performance on a previous task, they behaved in a more self-regarding manner compared to when they had been allocated to the more advantageous position randomly – presumably because earning the advantageous position made them feel entitled to a greater reward. I reasoned that if the intrinsic preference for fairness is more robust for effort than for money, then the manipulation of perceived legitimacy (whether they find themselves in the role of dictator because they earned it or because they were selected randomly) should have a larger effect on cooperativeness in the context of decision-making about money than in the context of decision-making about effort. I found an effect of perceived legitimacy, no effect of resource type and no interaction. This does not provide support for the resource-specific hypothesis. However, the results are consistent with previous research showing that increased perceived legitimacy tends to decrease participants' cooperativeness (Hoffman & Spitzer, 1982, 1985; Hoffman et al., 1994), and they extend the effect of legitimacy to the context of effort costs.

Taken together, the findings provide evidence for the hypothesis that the decision-making processes underlying people's distributive behaviour are resource-general in certain respects, and no clear evidence for the hypothesis that they may be resource-specific in other ways as well. With respect to the former (i.e., the resource-general hypothesis), the results

show that people share both effort and money more closely to an equal distribution in order to invest in potential direct or indirect reciprocity. With respect to the latter (i.e., the resource-specific hypothesis), the results, however, do not provide support for this conjecture.

Future Research

To what extent is the intrinsic motivation to share effort fairly shaped by genetic or experiential factors? One possibility is that people have genetic predispositions to share effort fairly because our ancestors acquired fitness benefits from reciprocating effort in repeated interactions, and with time, this eventually led to the selection of a disposition to be intrinsically motivated to share effort fairly. Alternatively, people may learn the benefits of sharing effort fairly from experience. Evidence in the context of decision-making about money points toward the latter hypothesis. For example, multiple studies have shown that intuitive cooperative responses are not universal (Rand et al, 2014; Tinghög et al., 2013). But this research has so far only probed the universality of fairness preferences when the resource at stake is money. One may speculate that people may have a genetic disposition to share effort fairly as well as a learned disposition to share money fairly. Future research could probe this conjecture, perhaps by investigating cross-cultural variability in people's intrinsic motivation to share effort fairly.

Conclusion and Further Directions

In this dissertation, I have aimed to create synergies between two different strands of research, i.e., between joint action research and evolutionary theories of cooperation. In doing so, I have endeavored to clarify a fundamental question: Why do people match their partner's effort? In other words, why would evolution have equipped us with such a tendency, and what are the proximate psychological mechanisms which underpin it? In providing answers to these questions, I hope to have enriched both strands of research with theoretical insights

and methodological innovations. In addition to this, I hope that my work will stimulate new questions.

With respect to joint action research, this dissertation has focused on an important new challenge for the field. Specifically, it has addressed how people decide how much effort to invest in a joint action. In doing so, I drew on recent research investigating the cognitive and motivational processes underpinning people's sense of commitment to performing actions together (Michael et al., 2016a; Michael et al., 2016b; Székely & Michael, 2018; Chennells & Michael, 2018; Chennells et al., 2022). The dissertation contributes to this research by specifying a proximate psychological mechanism that may be part of the psychological apparatus of the sense of commitment. In particular, our findings raise the possibility that the preference for achieving equity through effort calibration may be an important mechanism that boosts our motivation to perform actions together. And because we tend to match our efforts to that of others, we may also tend to expect it of each other. This may engender a positive feedback loop in which expectations and motivations to match our partner's effort reinforce each other, and this may stabilize the sense of commitment to performing actions together.

With respect to evolutionary theories of cooperation, this dissertation has focused on investigating the evolutionary origins and motivational mechanisms to cooperate in the context of joint action - where the main and ever-present resource at stake is *effort*. This is in contrast to most of the empirical studies in that tradition, which typically focused on the exchange of rewards (e.g., monetary resources) (Guala, 2005). This approach enabled me to generalize some important findings to the context of effort, such as the preference for fair distribution of rewards (Fehr & Schmidt, 1999; Frohlich et al., 2004; Cappelen et al., 2007), the effect of the expectation reciprocity (Herrmann et al., 2019; Engelmann et al., 2013;

Barclay & Willer, 2007; Dana et al., 2007), the stake size effect (Larney et al., 2019; Bechler et al., 2015; Engel, 2011) and the effect of legitimacy (Hoffman & Spitzer, 1982, 1985; McCabe et al., 1994). In addition, I put forward a hypothesis about why and how distributive preferences may differ based on the resource at stake. In short, I argued that because effort is a highly ubiquitous and important resource in everyday life now, as it has been throughout evolutionary history, decisions about the allocation of effort may be shaped by more robust intrinsic preference for fair distributions than decisions about the allocation of money. Although the results do not provide any clear evidence for this conjecture, it must be acknowledged that the experiments presented here tested the conjecture only within a highly circumscribed range of circumstances – economic games performed online and involving one particular form of effort (key presses). It may be fruitful for further research to test it with different kinds of effort contributions and/or in other settings.

To further clarify why and how people match their partner's effort, it would be an important next step to investigate this in ontogeny. Drawing on recent studies that have shown that three-year-old children take effort costs into account when they distribute the outcomes of a joint action (Hamann, Bender and Tomasello, 2014; Kanngiesser and Warneken, 2012), one may speculate that three-year-old children invest effort costs equally when they expect to share the reward of the joint task equally. Moreover, one may expect that children's tendency to match effort emerges earlier than their tendency to distribute outcomes according to effort costs, because in the latter case children also have to be able to skillfully compare different types of quantities.

Furthermore, some psychopathological conditions may reveal disruption in perceiving others' effort and responding appropriately. Some studies have already begun to explore individual variability in processing others' motivation, and to use this to gain a better understanding of social disorders. For example, Ooi et al. (2018) investigated the sense of

commitment in individuals with borderline personality traits in a non-clinical population and found that individuals with high levels of the traits associated with borderline personality disorder responded differently to commitment violations than individuals with low levels of the same traits. To map individual differences in processing others' effort, future work may draw upon the experimental tasks presented in this dissertation.

Non-human animals have also been shown to be sensitive to others' effort, and to calibrate their responses accordingly - although these studies do not involve joint action. For example, Wascher et al. (2013) tested whether crows and ravens are sensitive to a partner's effort in a token exchange task. They found that when required to work for a reward, the birds decreased their effort investment after having seen a second bird receive the same reward as a 'gift' (i.e. without work). The authors interpreted their findings as indicating that awareness of others' effort costs and benefits may have evolved independently of phylogeny in complex social systems. Future studies may probe to what extent non-human animals calibrate their effort investment in ongoing joint actions.

Our results may also inform the design of robots interacting with human partners. The prevalence of human-robot joint action is growing rapidly, and there is a vast potential for robots to assist humans in joint actions in wide range of domains, from disaster relief to health care. Programming robots to be sensitive to their partner's effort investment and to calibrate their effort investment to that of their partner may be a low-cost way to boost their partner's motivation in human-robot interactions. Indeed, preliminary evidence provides reason to be confident in this prospect. In previous studies (Székely et al., 2019; Vignolo et al., 2021, cues to the robot partner's higher effort investment elicited longer persistence in an increasingly boring task or increased adaptation in a teaching task. Thus, cues to a robot

partner's effort adjustment in the direction of that of their human partner's effort investment may boost their human partner's motivation in human-robot interactions.

Finally, the dissertation may inform philosophical work on joint action. In recent decades, there have been a number of proposals on what entails joint action (Gomez-Lavin & Rachar, 2019, 2021). Some philosophers - called normativists such as Margaret Gilbert (Gilbert, 2013) - say that normative relations such as entitlements and obligations are inherent in joint actions. Other philosophers - called non-normativists such as Michael Bratman (Bratman, 2013) - say that psychological attitudes such as shared intention are inherent in joint action and entitlements and obligations are not necessary. The present findings reveal subtle ways in which normativity pervades joint action, potentially even in cases in which parties to the joint action would not explicitly judge that obligations or entitlements are in place. As such, they provide a useful starting point for theorizing about the normativity of joint action.

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