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Evidence Against the Primacy of Energy Conservation: Exerted Force in Possible and Impossible Handgrip Tasks

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Abstract

Motivational intensity theory predicts that energy investment in goal pursuit is governed by the motivation to conserve resources and that it should consequently be a function of task demand: Trying to avoid wasting resources, individuals should invest only the energy that is required for task success and should disengage if success is impossible. Three experiments tested this hypothesis assessing the force exerted in an isometric handgrip task as indicator of energy investment. The results provided mixed evidence for motivational intensity theory. Supporting the theory, exerted force increased as a function of task demand if task success was possible and was low if success was impossible. However, exerted force exceeded required force in all possible conditions and participants did not disengage if task success was impossible. A meta-analysis of published studies involving disengagement conditions revealed that preceding research on motivational intensity theory also failed to provide support for the disengagement hypothesis. Our findings demonstrate the importance of task demand for energy investment but also challenge the assumption that energy investment is primarily driven by energy conservation concerns.

Keywords: motivational intensity theory, goal pursuit, energy conservation, energy investment, task difficulty, disengagement, handgrip task

Evidence Against the Primacy of Energy Conservation: Exerted Force in Possible and Impossible Handgrip Tasks

Many theories on effort rely on the idea that effort or resource investment is driven by energy conservation concerns (e.g., Ach, 1910; Hull, 1943; Zipf, 1949). They assume that organisms try to minimize the energy that they invest in a task because they are motivated to avoid wasting resources and postulate that organisms aim at investing only the energy that is required. Motivational intensity theory (Brehm & Self, 1989) draws explicitly on this energy conservation principle to derive predictions for energy investment in goal pursuit. According to the theory, task difficulty and importance of success jointly determine energy investment or effort in instrumental tasks (i.e., tasks that allow the individual to attain a goal). Energy investment should be proportional to task difficulty if task success is possible and if the necessary energy investment is justified by the importance of task success. If success is impossible or if the importance of success does not justify the required energy investment, individuals should disengage and refrain from investing energy in the task.

Most of the research on motivational intensity theory has relied on self-reports or cardiovascular measures to test the theory's predictions (e.g., Brehm, Wright, Solomon, Silka, & Greenberg, 1983; Brinkmann, Franzen, Rossier, & Gendolla, 2014; Franzen & Brinkmann, 2016; Richter, Baeriswyl, & Roets, 2012; Richter & Gendolla, 2009; Silvia, Nusbaum, Eddington, Beaty, & Kwapil, 2014; see Richter, Gendolla, & Wright, 2016, for a recent review). Despite the virtue of these measures, they are ambiguous indicators of energy-related processes (e.g., Marcora, 2009; Sherwood, Allen, Obrist, & Langer, 1986) and preceding work relying on them can only provide preliminary evidence for motivational intensity theory's energy-related predictions (see the discussion section for a more detailed discussion of the relationship between self-reports, cardiovascular measures, and energy investment). Recently, Richter (2015) suggested an empirical paradigm that enables more focused tests of motivational intensity theory's energy-related hypotheses by using exerted muscle force in an isometric handgrip task as an indicator of energy investment.

According to sliding filament theory (Huxley, 1974), muscle contraction is caused by the interaction of the molecules actin and myosin. During contraction, myosin heads bind to actin causing a sliding of actin past myosin that shortens the muscle and produces force. The higher the number of myosin heads that bind to actin, the higher the force exerted by the muscle. Given that each myosin-actin binding consumes one molecule of adenosine triphosphate (ATP)–the primary energy source for human action (Sherwood, 2010)–exerted force and ATP consumption should be related. Empirical studies provided evidence for this theoretical perspective by demonstrating the proportional relationship between ATP consumption and exerted force in isometric tasks (e.g., Boska, 1994; Russ, Elliott, Vandenborne, Walter, & Binder-Macleod, 2002). Given that the economy of muscle contraction depends on many factors (e.g., muscle fibre type, contraction speed, see Russ et al., 2002, Stienen, Kiers, Bottinelli, & Reggiani, 1996), exerted force does not indicate absolute energy consumption. However, under controlled conditions exerted force enables inferences regarding the relative amount of invested energy. If an individual exerts a low force of 50 Newton (N) in the first trial of a task and, under the same conditions, 100 N in the second trial, it is likely that she or he expended more energy in the second trial than in the first one. Exerted muscle force in isometric tasks (i.e., tasks where the muscle contracts without a change in muscle length) consequently reflects the relative amount of energy that is invested in the task and enables focused tests of motivational intensity theory's energy-related hypotheses.

In his study, Richter (2015) manipulated the difficulty of an isometric handgrip task across four levels to examine motivational intensity theory's prediction that task difficulty determines energy investment. Corroborating the hypothesis, exerted force increased with increasing task difficulty in a proportional manner: The higher the difficulty, the higher the exerted force. However, there were also some unexpected findings that were in conflict with motivational intensity theory. Participants exerted always more force than required, conflicting with the hypothesis that individuals invest only the required energy and not more. The work presented in this paper aimed at replicating and extending Richter's results by comparing energy investment in possible and impossible tasks.

According to motivational intensity theory, energy investment should only be proportional to task difficulty if task success is possible. If task success is impossible, individuals should disengage and invest no energy. It is therefore crucial to compare energy investment in possible and impossible tasks for a comprehensive test of the theory. An impossible task also provides the opportunity to conduct a strong test of the hypothesis that energy investment is governed by energy conservation concerns. Performing impossible task trials should provide participants with unambiguous information regarding the feasibility of the task. After repeated failures, participants should have learned that task success is impossible and, if energy investment is primarily driven by energy conservation concerns, they should disengage. To examine these hypotheses we conducted three experiments that compared an impossible task difficulty condition with one (Study 1) or three (Study 2 and Study 3) difficulty levels where task success was possible. Drawing on motivational intensity theory, we predicted that energy investment—assessed as exerted grip force—increases as a function of task difficulty in the possible task difficulty conditions. In the impossible conditions, we expected that participants disengage and do not invest any energy.

Study 1

Method

Participants and design. Fifteen women participated voluntarily and anonymously, and received 10 Swiss Francs (corresponding to 10 USD) for their participation (mean age = 25.53, *SE* = 1.42). They performed an isometric handgrip task under two difficulty conditions (easy vs. impossible) in a within-persons design.

Apparatus and measurement. The experiment was programmed using LabVIEW 2009 software (National Instruments, Austin, TX, USA). The software controlled the presentation of instructions and the randomization of the difficulty conditions and assessed the force that participants exerted on a dynamometer (HD-BTA by Vernier Software and Technology, Beaverton, OR, USA). Exerted force (in N) was sampled at 10 Hz. The dynamometer was fixed at the computer desk at the side of the participant's dominant hand and at the level of the chair armrests.

Procedure. The experiment lasted 20 minutes. It was run in individual sessions. After having provided informed consent, participants read a brief description of the experiment and completed a demographic questionnaire (gender, native language, age, study level, dominant hand). They could then familiarize themselves with the dynamometer during thirty seconds. During this period participants could squeeze the dynamometer at will and the force that they were exerting was displayed in real time on a screen. After the familiarization period, participants were informed that they would perform two different handgrip tasks. In the first one, their maximum force would be determined. In the second one, they would have to attain a fixed force standard. Participants were instructed to perform all handgrip tasks with their dominant hand.

In both tasks, the trials followed the same structure. Each trial started with a countdown of six seconds followed by a measurement period of two seconds, during which the force that participants exerted on the dynamometer was assessed, and a feedback period of four seconds. In the first task, participants were asked to attain a certain force standard at least once during the measurement period. They learned that the requested force would be 25 N in the first trial and that the force standard would increase in each following trial by 25 N. In the last trial, the force standard would be 500 N. Participants read that, at some point, the requested force would exceed their maximal force and that they should feel free to refrain from squeezing if they felt that they would not be able to attain the requested force. The respective force standard of a trial was displayed on the screen during the countdown period. A feedback after the measurement period informed participants whether they had attained the force standard or not.

After having performed the 20 trials of the first task, participants received the instructions for the second task. They read that the second task would be similar to the first one with one exception: The force standard would not increase across trials but the computer would randomly choose for each trial a force standard from the force standards presented in the first task. Participants then performed 20 trials including 10 trials with a force standard of 100 Newton and 10 trials with a force standard of 500 Newton presented in random order. As in the first task, the force standard of the upcoming measurement period was displayed during the countdown period, and participants received a feedback after each measurement period.

After having performed the second task, participants were debriefed and received their remuneration.

Data analysis. The highest force exerted during the first task constituted our measure of participants' maximum force. For each trial of the second task, we determined the exerted peak force (i.e., the maximum value of the obtained twenty force values) as an indicator of invested energy. If a participant engages and squeezes the dynamometer, peak force is greater than zero. If a participant disengages and does not at all squeezes the dynamometer, peak force equals zero. We also computed a second indicator of energy investment, force-time integrals (FTI, Filion, Fowler, & Notterman, 1970), by summing up all twenty force values of a trial. FTIs reflect the total energy investment across the two seconds of measurement. However, given that FTIs were not instrumental for success—peak force was compared to the force standard to determine task success—they constituted only our secondary dependent variable. We aggregated peak force and FTI values within each difficulty condition by calculating the arithmetic mean of peak force and FTI values of all trials of a difficulty condition.

We tested our energy-related predictions using Bayesian *t*-tests (Rouder, Morey, Speckman, & Province, 2012; Rouder, Speckman, Sun, Morey, & Iverson, 2009). Bayesian *t*-tests are the Bayesian equivalent to conventional frequentist *t*-tests. Instead of resulting in a *p*-value, Bayesian *t*-tests provide Bayes Factors that describe the likelihood of the data under the null hypothesis of no difference compared to the likelihood of the data under the alternative hypothesis of a difference. Bayesian *t*-tests thus indicate the relative evidence for the null hypothesis compared to the alternative hypothesis. In contrast to *p*-value based hypothesis tests, which cannot provide provide evidence for the null hypothesis (e.g., Dixon, 2003; Johansson, 2011), Bayesian *t*-tests enable the quantification of evidence for no difference.

We conducted four Bayesian *t*-tests to examine our predictions. First, two one-tailed Bayesian *t*-tests for dependent samples compared peak force and FTI values between the easy and the impossible conditions to test the predicted impact of task difficulty on exerted force. Second, two two-tailed one-sample Bayesian *t*-tests addressed the hypotheses that individuals invest only the energy that is required for task success and that they disengage if task success is impossible. The first test compared the force exerted in the easy condition with the force standard required for success (100 N). The second test compared the force exerted in the impossible condition with a value of 0 N. All Bayesian *t*-tests (and associated scaled JZS Bayes Factors) were computed in R with the BayesFactor package (Morey & Rouder, 2015) and interpreted using the nomenclature of Raftery (1995).

Results

Mean peak force exerted during the first task was 197.74 N (*SE* = 16.48). The highest force exerted by a participant in the first task was 298.25 N. In the second task, mean peak force was 184.27 N (*SE* = 14.70) and the highest force exerted was 291.79 N. The Bayesian *t*-test comparing the peak force exerted during the second task between the easy and the impossible conditions resulted in a *BF* of 6.76 providing positive evidence for the hypothesis that participants exert more force in the easy condition than in the impossible condition. Cell means and standard errors were *M* = 135.40 and *SE* = 11.10 in the easy condition and *M* = 75.94 and *SE* = 22.28 in the impossible condition. Figure 1 displays this pattern. The Bayesian *t*-test resulted in a *BF* of 4.58 for FTI scores. FTI cell means and standard errors were *M* = 1663.26 and *SE* = 159.73 in the easy condition and *M* = 1014.21 and *SE* = 302.87 in the impossible condition.[1]

Contrary to the predictions of motivational intensity theory, we did not find evidence for disengagement or that participants invested only the force required. The one-sample Bayesian *t*-tests provided a *BF* of 7.88 for the comparison of exerted force with the required force of 100 N indicating positive evidence against the hypothesis that participants invest exactly the required force. The comparison of exerted force with 0 N provided a *BF* of 11.37 indicating positive evidence against the hypothesis that participants disengage.

Discussion

The results of Study 1 corroborated the predicted impact of task difficulty on exerted force and energy investment. Participants exerted less force in the impossible condition than in the easy condition. However, even if participants decreased their force in the impossible condition compared to the easy, possible condition, we did not find evidence for disengagement. Participants were unable to succeed in the impossible task but they nevertheless squeezed the dynamometer. Moreover, replicating Richter's (2015) results, we found that participants exerted in the easy condition a higher force than required. The findings of Study 1 provided clear evidence for the impact of task difficulty on energy investment predicted by motivational intensity theory but they also provided evidence that challenges the theory's prediction that energy investment is primarily driven by energy conservation concerns.

Study 2 and 3

1 *P*-value based *t*-tests were $t(14) = 2.67$, $p = .009$, $d = 0.98$, for peak force and $t(14) = 2.43$, $p = .01$, $d = 0.88$, for FTI.

To test motivational intensity theory's predictions regarding the impact of task difficulty on energy investment in a more comprehensive manner, we conducted two additional experiments that manipulated task difficulty across four levels (easy, moderate, difficult, and impossible) in a between-persons (Study 2) and a within-persons design (Study 3). Drawing on motivational intensity theory, we expected in both studies an increase in exerted force and invested energy across the three possible difficulty conditions and disengagement (i.e., no energy investment) in the impossible difficulty condition.

Method

Participants and design. Eighty first-year psychology students (mean age = 20.98, *SE* = 0.46) of the University of Geneva participated voluntarily and anonymously in Study 2 and received course credit for their participation.[2] They were randomly assigned to one of four task difficulty conditions (easy, moderate, difficult, and impossible). The distribution of men and women was as follows: 2 men and 18 women in the easy condition, 5 men and 15 women in the moderate condition, and 3 men and 17 women in both the difficult and impossible condition. 20 psychology students participated in Study 3 (8 men and 12 women, mean age = 24.45, *SE* = 1.61).[3] They received 10 Swiss Francs (about 10 USD) for their participation. Participants performed each one of the four conditions (easy, moderate, difficult, and impossible).

Procedure. The equipment in Study 2 and 3 was the same as in Study 1. Both studies followed the procedure of Study 1 with the following exceptions. First, there was only

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2 Eighty-one students participated in Study 2 but the data of one participant were excluded because he was able to succeed in the impossible condition. Inclusion of this participant did virtually not change the results.

3 Twenty-one students participated in Study 3 but the data of one participant were excluded because he was able to succeed in the impossible condition. Inclusion of this participant did virtually not change the results.

one handgrip task in the task period. Second, the task allowed participants to accumulate small monetary rewards. The handgrip task was introduced using a cover story. Participants learned that they should imagine that they were squeezing a clogged Ketchup bottle to free it. If they squeezed the bottle (the dynamometer) hard enough, they would free the bottle. To support this cover story, a black and white drawing of a hand holding a reversed Ketchup bottle was displayed during the task trials. Furthermore, participants learned that every time that they would free the bottle, they would earn a small monetary reward of 0.05 Swiss Francs (about USD 0.05). If the force exerted during the measurement period matched or exceeded the requested force, participants received a visual feedback showing a hand squeezing a Ketchup bottle that ejects Ketchup and a picture of a 0.05 Swiss Francs coin. If participants did not exceed the force standard during the squeezing period, the drawing did not change during the feedback period. To present the appropriate feedback, exerted peak force during the squeezing period was compared to the force standard. The exerted peak force was displayed during the feedback period.

The force standard that participants had to exceed to free the bottle and to earn the reward was displayed during the entire trial on top of the screen. The force standards used in the two studies were 50, 100, 150, and 500 Newton corresponding to a low, moderate, difficult, and impossible difficulty. In Study 2, participants were informed before the beginning of the handgrip task that the force standard would be randomly chosen at the beginning of the task. Participants performed only one of the four difficulty conditions. In Study 3, participants learned that the force standard would vary from trial to trial. In both studies, participants were informed that the force standard could exceed their maximal grip force and that they should feel free to refrain from squeezing the dynamometer.

The handgrip task included five blocks, each one composed of several trials and preceded by a pause of 30 seconds. The first four blocks served as practice period to learn about the difficulty of exerting a certain force. The fifth block constituted the period of interest and force values assessed during this block were used for the statistical analysis. In Study 2, each block included 10 trials. In Study 3, each block included 20 trials, five trials for each one of the four difficulty conditions. The order of presentation of the difficulty conditions was randomized within each block.

Data analysis. Exerted force during the fifth block was used for the statistical analysis. The data analysis followed Study 1. We determined for each trial the peak force as well as the FTI and computed mean peak force and mean FTI values for each difficulty condition. Peak force and FTI values were then analyzed with a planned contrast (contrast weights were -1 for the easy condition, +1 for the moderate condition, +3 for the difficult condition, and -3 for the impossible condition) to test the predicted impact of task difficulty on exerted force (Glover & Dixon, 2004; Masson, 2011; Richter, 2016; Rosenthal, Rosnow, & Rubin, 2000). One-sample Bayesian *t*-tests were used to test the predictions that individuals invest exactly the required force and that individuals disengage if task success is impossible. As in Study 1, exerted peak force constituted our primary dependent variable given that exerted peak force determined task success.

Results

Study 2. Mean peak force exerted during the five blocks was 158.74 (*SE* = 5.76). The highest force exerted by a participant during the five blocks was 456.39 N. The comparison of the predicted model (i.e., the planned contrast) with the null model resulted in a *BF* of 2.56 providing positive evidence in favor of the predicted pattern. Peak force was *M* = 120.34 (*SE*

= 12.97) in the easy condition, *M* = 152.80 (*SE* = 8.19) in the moderate condition, *M* = 176.53 (*SE* = 7.10) in the difficult condition, and *M* = 145.50 (*SE* = 13.43) in the impossible condition. Figure 2 shows the pattern of exerted peak force. For FTI values, the model comparison did not provide evidence for the predicted pattern (*BF* = 1.03). Cell means and standard errors were *M* = 1682.97 and *SE* = 215.41 in the easy condition, *M* = 2142.98 and *SE* = 190.68 in the moderate condition, *M* = 2652.41 and *SE* = 161.27 in the difficult condition, and *M* = 2131.90 and *SE* = 255.75 in the impossible condition.[4]

Contrary to the predictions, Bayesian *t*-tests comparing exerted peak force with the force standard provided strong to very strong evidence that participants exerted more force than required (*BF* = 790.85 in the easy condition, *BF* = 5672.11 in the moderate condition, *BF* = 27.42 in the difficult condition). Moreover, a comparison of the exerted force in the impossible condition with 0 N resulted in a *BF* of 77.00 x 10^{5}, providing very strong evidence against the hypothesis that participants disengage when task success is impossible.

Study 3. Participants' mean peak force during the five blocks of the task was 152.84 N (*SE* = 7.72). The highest force exerted by a participant was 402.62 N. The comparison of the predicted model with the null model resulted in a *BF* of 59.98 x 10^{12} providing very strong evidence in favor of the predicted impact of task difficulty on exerted peak force. Participants exerted a force of *M* = 138.35 (*SE* = 6.84) in the easy condition, *M* = 156.58 (*SE* = 5.68) in the moderate condition, *M* = 177.53 (*SE* = 4.56) in the difficult condition, and *M* = 68.50 (*SE* = 16.73) in the impossible condition. Figure 3 shows the pattern of exerted peak force. The comparison of the predicted model with the null model also provided very strong evidence

4 *P*-value based tests of the planned contrast resulted in $t(76) = 2.60$, $p = .006$, $MSE = 2329.67$, $d = 0.60$, for peak force and $t(76) = 2.17$, $p = .02$, $MSE = 87.09 \times 10^{4}$, $d = 0.60$ for FTI.

for the predicted impact of task difficulty on FTI, *BF* = 18.69 x 10^9.[5] Cell means and standard errors were *M* = 1622.34 and *SE* = 150.83 in the easy condition, *M* = 1959.34 and *SE* = 142.16 in the moderate condition, *M* = 2367.17 and *SE* = 161.60 in the difficult condition, and *M* = 952.21 and *SE* = 280.22 in the impossible condition.

Replicating Study 1 and Study 2 but in conflict with motivational intensity theory, Bayesian *t*-tests found very strong evidence against the prediction that participants invest only the force required for task success (*BF* = 12.28 x 10^7 in the easy condition, *BF* = 21.65 x 10^5 in the moderately difficult condition, *BF* = 2608.69 in the difficult condition). There was also strong evidence against the prediction that participants disengage if task difficulty is impossible, *BF* = 55.76.[6]

Discussion and meta-analysis of preceding studies including a disengagement condition

Study 2 and 3 replicated the findings of Study 1. We found support for the predicted impact of task difficulty on energy investment: Exerted force increased across the three possible conditions and dropped in the impossible condition. However, we again failed to provide support for the hypotheses that individuals invest only the required energy and disengage if task difficulty is too high. Participants invested more than required and did not disengage even if they knew that task success was impossible. This failure to find supporting evidence seemed to sharply contrast with preceding publications on motivational intensity theory that ostensibly provided overwhelming evidence in favor of the theory. We therefore took a closer look at preceding publications to work out whether our findings actually conflict

5 *P*-value based tests of the planned contrast resulted in $t(57) = 7.25$, $p < .001$, $MSE = 1305.93$, $d = 2.53$, for peak force and $t(57) = 5.62$, $p < .001$, $MSE = 39.67 \times 10^{4}$, $d = 1.93$, for FTI.

6 Four of the participants in Study 3 showed mean peak force values smaller than 1 N in the impossible condition, which could be interpreted as disengagement. There was no evidence for disengagement in Study 2. The lowest individual mean peak force in the impossible condition was 52.51 N.

with preceding work or whether preceding work missed to acknowledge observed conflicting evidence. Given that most of the empirical literature on motivational intensity theory has used systolic blood pressure and pre-ejection period as main dependent variables, we focused our analysis on these two cardiovascular parameters.

A literature search in four databases (ERIC, PsycARTICLES, PsycINFO, Medline) and Google Scholar using the key words “motivational intensity theory” and “cardiovascular” generated 55 published studies that included one or more conditions where the authors expected disengagement (either because of task success considered to be impossible or because of the required effort considered not to be justified by the importance of task success). 40 of these studies provided information about mean systolic blood pressure reactivity—the change from rest to task performance—in the disengagement condition as well as the associated within-condition variance and the condition sample size. 11 studies provided this information for pre-ejection period reactivity. Table 1 indicates these studies and the respective disengagement conditions. The data of the disengagement conditions were analyzed meta-analytically. If there was more than one disengagement condition in a study, the conditions were aggregated to obtain a single pooled disengagement mean and variance.

Given that the systolic blood pressure and the pre-ejection period of a disengaged participant should not differ from resting values, we computed for each study and parameter a *t*-value comparing the mean reactivity in the disengagement condition to a value of zero. These *t*-values were then aggregated using the method described by Rouder and colleagues (Rouder & Morey, 2011; Rouder, Morey, Speckman, & Province, 2012) to obtain a Bayes Factor that reflected the relative evidence for the hypothesis that individuals do not disengage (that they show a systolic blood pressure reactivity greater than 0 or a pre-ejection period reactivity less than 0) compared to the evidence for the hypothesis that individuals disengage. Bayes Factors were computed in R using the BayesFactor package (Morey & Rouder, 2015).

For systolic blood pressure reactivity, the resulting *BF* was 1.47 x 10^{56} with individual *t*-values ranging from -1.92 to 8.88.[7] For pre-ejection period reactivity, the *BF* was 57.78 with individual *t*-values ranging from -4.34 to 1.60. These *BF*s provided strong to very strong evidence in favor of no disengagement and against motivational intensity theory's prediction that individuals disengage if task success is too difficult.[8] Preceding empirical research thus already provided findings that conflicted with motivational intensity theory's predictions and that are in line with our findings. Researchers probably missed these contradicting findings because they focused on the overall pattern of condition means and did not specifically examine whether there is any evidence for the predicted disengagement if task difficulty is too high.

Unfortunately, it is not possible to apply the same analysis strategy to find out whether preceding empirical research has also already found evidence that individuals invest more than required. The main reason for this is that cardiovascular measures do not enable a comparison of exerted energy (or effort) with required energy (or effort). If one observes that a participant shows a systolic blood pressure increase of 10 mmHg from rest to task performance, one does not know if this increase exceeds the required increase or not. It is impossible to know whether the increase of 10 mmHg was required to successfully perform the task or if a smaller increase would also have been sufficient. It is thus impossible to use

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7 A reviewer noted that some of the variation in the size of the observed effects might be explained by the different measurement devices used in the studies.

8 As a reviewer pointed out, this only applies if participants in the studies actually perceived the tasks as being too difficult.

the published studies on motivational intensity theory to address this question. The presented studies and the studies presented in Richter’s (2015) article constitute the first studies that enabled a direct test of the prediction that individuals invest only the required energy.

General Discussion

The presented three studies provided mixed evidence for motivational intensity theory. On the one hand, they consistently demonstrated the predicted relationship between task difficulty and energy investment: Exerted force increased with increasing task difficulty if success was possible and was low if success was impossible. This finding is consistent with preceding empirical work on motivational intensity theory that has demonstrated the impact of task difficulty on cardiovascular responses (e.g., Richter, Friedrich, & Gendolla, 2008; Wright, Dill, Geen, & Anderson, 1998). On the other hand, our studies revealed two findings that conflict with motivational intensity theory's postulate that individuals are primarily guided by energy conservation concerns. First, participants exerted in all studies a higher force than required in the conditions where success was possible. Second, participants invested energy in impossible tasks. Even if they had repeatedly made the experience that task success was impossible—in Study 2, participants performed 50 impossible trials—participants did not disengage.

These findings conflict with the theoretical predictions but they do not conflict with the existing empirical research on the theory. Research that examined whether individuals invest exactly the energy required for task success does not exist given that the employed self-report and cardiovascular measures did not enable a comparison with what was minimally required. However, research on emotional intensity theory (Brehm, 1999) has produced indirect evidence for excess energy investment (Pantaleo, 2011; Pantaleo, Miron, Ferguson, & Frankowski, 2014). For instance, Pantaleo and colleagues (Pantaleo et al., 2014, Study 2) found that the intensity of group identification was a function of the difficulty of attaining a group goal: Group identification increased from low goal difficulty to moderate goal difficulty and was low if goal difficulty was high. In a control group, where no information about the difficulty of attaining the group goal was provided, group identification was high. This pattern of results corresponds to emotional intensity theory's predictions but Pantaleo and colleagues also observed conflicting findings. They observed that in the control and the high difficulty groups emotion intensity (the intensity of group identification) increased compared to a baseline measure. If one considers the felt emotion intensity before the presentation of the goal deterrent to reflect the maximally justified intensity, the intensity increase in the control and the high difficulty groups might be interpreted as evidence for excess emotion intensity. Given that Brehm (1999) suggested that the cognitive, physiological, and behavioral systems respond proportionally to emotion intensity, Pantaleo and colleagues findings can be considered to provide indirect evidence for excess energy investment.

Research involving conditions in which disengagement was expected exists but it did not specifically test whether participants in these conditions actually invested no energy. Our meta-analysis of the data of these studies demonstrated that they provided very strong evidence that individuals do not completely disengage. Preceding studies on motivational intensity thus also failed to provide evidence for motivational intensity theory's prediction that individuals disengage if task difficulty is too high (for illustrative examples, see Freydefont, Gendolla, & Silvestrini, 2012; Wright, Brehm, Crutcher, Evans, & Jones, 1990; or Wright, Shaw, & Jones, 1990).

It is noteworthy that our exerted force measure and our findings cannot be related to the earliest cardiovascular studies on motivational intensity theory (e.g., Wright, Contrada, & Patane, 1986; Wright & Gregorich, 1989). These studies assessed cardiovascular responses immediately before task performance but not during task performance. They thus did not examine the energy that was actually invested in the task but anticipatory responses. These responses might reflect the preparation of action or the mobilization of resources but they clearly do not reflect the same process as our exerted force measure. Exerted force does not reflect the preparation of an instrumental action, it is a crucial element of the instrumental action itself.

The use of exerted force to test motivational intensity theory' predictions had two main advantages. First, it enabled us to test the prediction that individuals invest exactly the energy that is required. Second, the measure enabled a more precise test of motivational intensity theory's energy-related predictions than self-reports or cardiovascular measures—the measures that have been used in preceding work on the theory. In contrast to these measures, exerted force is a direct indicator of invested energy. Studies on the perception of effort questioned the utility of self-reported effort as an indicator of energy investment by demonstrating that the association between self-reported effort and energy investment can be low (Marcora, 2009, for a review). Research on Obrist's cardiac-somatic uncoupling hypothesis provided evidence that cardiovascular measures and energy investment may be dissociated under certain conditions (e.g., Brod, 1962; Hickam, Cargill, & Golden, 1947; Obrist, 1981; Sherwood et al., 1986). Obrist (1981) suggested that mental tasks that allow the individual to attain positive consequences or to avoid negative consequences are characterized by cardiac-somatic uncoupling—a dissociation of the activity of the cardiovascular system from metabolic (energy-related) demands.

In one of the studies on cardiac-somatic uncoupling, Sherwood and colleagues (1986) measured oxygen consumption—an indicator of energy consumption—and cardiovascular reactivity under three task conditions. Participants immersed their foot in ice water in a passive aversive task, pedalled at three different workloads on a cycle ergometer, and pressed a key as fast as possible to avoid electrical shocks in an active aversive task. Sherwood and colleagues observed that cardiovascular reactivity and oxygen consumption were associated in the first two tasks but not in the active aversive task. In this task, cardiovascular reactivity largely exceeded energy consumption. Cardiovascular responses thus do not enable valid conclusions regarding energy investment. In contrast to self-reports and cardiovascular responses, exerted muscle force in handgrip tasks is closely related to the amount of energy (ATP) consumed for muscle contraction (e.g., Boska, 1994; Russ, Elliott, Vandenborne, Walter, & Binder-Macleod, 2002). Under controlled conditions, a higher exerted force is indicative of a higher energy investment. Exerted muscle force therefore enables more specific tests of motivational intensity theory's energy-related hypotheses than self-reports or cardiovascular measures. It is, however, noteworthy that using exerted muscle force limits the tasks that can be used. The measure of exerted force requires physical tasks and leaves open whether the observed findings generalize to other (cognitive) tasks.

One might wonder whether the findings that challenge motivational intensity theory are methodological artifacts or the result of failed manipulations. For instance, one might presume that individuals exerted a higher force than required and did not disengage because they did not exactly know what was minimally required. The number of practice trials that they performed might not have been sufficient to enable participants to develop a clear understanding of what was required to succeed. Alternatively, one might suggest that the fatigue induced by performing the hand grip task induces ambiguity about the amount of energy that is required for the next trial. Presented as a general post-hoc explanation, it is difficult to counter this argument. There is some evidence that suggests that participants easily learn to exert a specific grip force in our handgrip paradigm. Fifteen practice trials were sufficient in Richter’s (2015) studies to enable participants to exert a required force with a high level of precision. Moreover, the difficulty effect that we observed in all studies provides some evidence that participants had acquired sufficient information about task difficulty. It is also noteworthy that one would expect exerted force values to vary more if participants merely lacked precise information about the minimally required force. Force values should have been distributed on both sides of the force standard. In some trials, participants should have invested a higher force than required. In other trials, they should have invested less than required. The observation that participants rarely invested less than required (in the possible conditions) questions the notion that participants merely did not have enough information about what was required to succeed.

The strongest argument against the explanation that our findings are due to unclear task demand is that this explanation does not help to reconcile our findings with motivational intensity theory. Motivational intensity theory predicts that success importance is the sole determinant of energy investment if task demand is unclear. Task difficulty should not have any impact. If we assume that our effects were due to unclear task difficulty, motivational intensity theory does not offer any explanation for the observed impact of task difficulty. The explanation that participants exerted a higher force than required and that they did not disengage because of a lack of precise information about the required force might thus provide an explanation of the results that conflict with motivational intensity theory but it constitutes an explanation that conflicts itself with motivational intensity theory.

A second explanation that one might be tempted to put forward is that participants invested more than required and engaged in impossible tasks because they were convinced that the experimenter expected them to engage in the task. Our participants might have assumed that the experimenter wanted them to squeeze the dynamometer in each trial and tried to be good participants by corresponding to the experimenter's expectations. We tried to attenuate this potential problem by repeatedly stating in the task instructions that the required force might exceed participants' maximum force in some trials and that participants should feel free to refrain from exerting any force in these trials. However, we cannot prove that all participants followed our instructions. Participants might have ignored the task instructions and adopted other goals like always squeezing the dynamometer to appear as a good participant or squeezing the dynamometer just for fun.

It is important to be aware that such a post-hoc explanation is of limited value. It can be applied to any contradicting finding to save motivational intensity theory. Whenever one observes that individuals invest more than required or do not disengage, one may attribute this to the fact that participants did not follow the task instructions but did something else. Using such a line of argument one has never to reject motivational intensity theory's prediction that individuals invest only the required effort because one always has an explanation at hand that saves the theory. One ends up in a situation where one never questions the validity of the prediction because one will never accept conflicting evidence.

It seems more promising to use the present findings as a jumping-off point for further theoretical development. Our results do not call into question that energy conservation is an important mechanism that influences energy investment. If participants had not been concerned about conserving energy, they would have always invested the same amount of energy. They would not have reduced the amount of energy invested in the easy and impossible conditions compared to the energy invested in the difficult conditions. However, our findings—and the findings of the studies summarized in our meta-analysis—question the primacy of this mechanism. The motivation to avoid wasting energy might not be sufficient to explain energy investment.

One might wonder why Brehm postulated a single motivational mechanism and why this mechanism focuses on explaining why individuals avoid investing (much) energy. The theory seems to lack a mechanism that explains why individuals do invest energy. An inspection of Brehm’s first draft of the theory (Brehm, 1975) reveals that his theory actually includes both a ‘positive’ mechanism that explains why individuals invest energy and a ‘negative’ mechanism that explains why they try to minimize the invested energy. He considered the need state of the individual and the individual’s goal to be the factors that push the individual to invest energy. He suggested that these variables determine directly the maximum of motivation (he used maximum motivational arousal and maximally justified energy as synonyms). He, however, also suggested that this maximum motivation is suppressed as a function of task demand when individuals perform instrumental actions to satisfy their needs or to attain their goals.

Brehm argued that this suppression occurs for three reasons. First, it avoids wasting resources that are crucial for survival. Second, it prevents negative physiological (health) problems that can result from excess motivational arousal. Third, it impedes psychological problems (for instance, frustration) that can be a consequence of excess arousal in situations where success is impossible. Suppressing motivational arousal—that is, investing less energy than maximally justified—thus enables the individual to avoid wasting resources and to avoid negative physiological and psychological consequences. It is evident from these explanations that Brehm's theory includes a mechanism that explains why individuals invest energy. However, the focus on the suppression of motivation, led to a theory that is not primarily interested in explaining why individuals invest energy but in one that focuses on why individuals invest less than their maximally justified energy.

One way to deal with the conflicts between motivational intensity theory's predictions and our findings might be to propose a new theoretical account that emphasizes the mechanisms that explain why individuals invest energy. One might, for instance, speculate that most tasks involve some kind of vagueness regarding the exact amount of required energy. Individuals might have a rough idea of what is required but do not know exactly how much energy they need to invest. If individuals are aware of this, they might choose to invest always a little bit more energy to assure success. This would explain the difference between required and exerted force that we observed in our studies but it would not be able to explain the lack of disengagement observed in our studies and the cardiovascular studies.

An alternative is to drop motivational intensity theory's notion that one either invests the required energy or does not invest anything at all. Instead of postulating such a dichotomy, one might postulate a continuum from no energy investment over some energy investment to the investment of all available energy. One might further hypothesize that individuals consider the probability of successfully performing a task to be a function of the amount of invested energy. Investing a low amount of energy, leads to a low likelihood of successfully performing the task. Investing a high amount of energy, leads to a high likelihood. Individuals might thus be motivated to invest a high amount of energy to maximize the probability of goal attainment. At the same time, they might be interested in investing a low amount of energy to avoid wasting resources. Such a two-motivational-mechanism model can explain the lack of disengagement that we found. Even if one considers a task to be extremely difficult, one might give it a try and invest a low amount of energy. One might be lucky and succeed. If one fails, one did not waste a lot of energy.

The ideas that we have set out in the preceding paragraphs need to be formalized and presented as a coherent theoretical model before their utility can be evaluated. Such an alternative model would constitute a significant scientific advancement if it were able to account for all the findings explained by motivational intensity theory as well as for additional findings that cannot be explained by motivational intensity theory (for instance, our findings that individuals do invest more than required and that they do not completely disengage in impossible tasks). Developing an alternative to motivational intensity theory would help researchers to adopt a less ‘biased’ approach when examining energy (or effort) investment. Instead of aiming at finding supporting evidence for single theory, they could design decisive experiments to compare competing theories (Platt, 1964). The results of our studies as well as the meta-analysis of the cardiovascular disengagement studies demonstrated that motivational intensity theory’s explanatory power is limited and that the development of new perspectives on energy investment is needed. We hope that our article fosters new endeavors to critically analyze existing perspectives on energy and effort investment in goal pursuit and to develop alternative theories.

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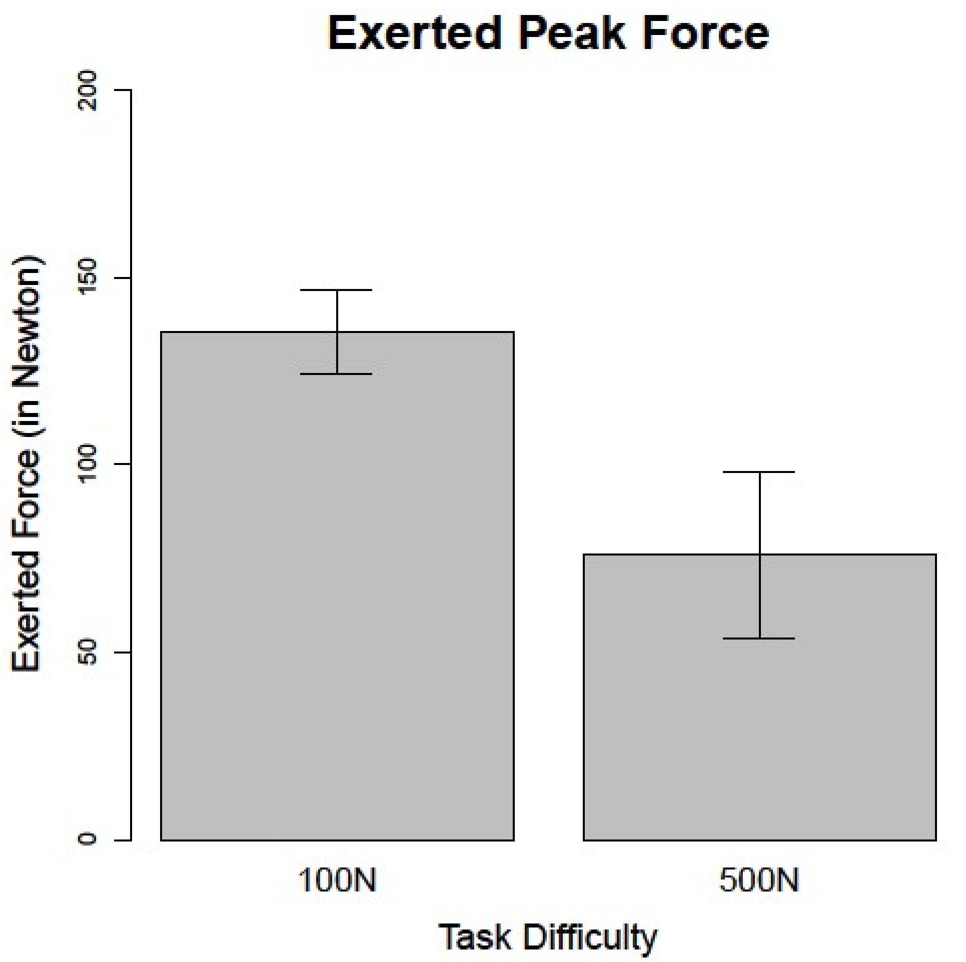

Figure 1. Means of exerted peak force (in Newton) during the second task of Study 1. Error bars represent standard errors.

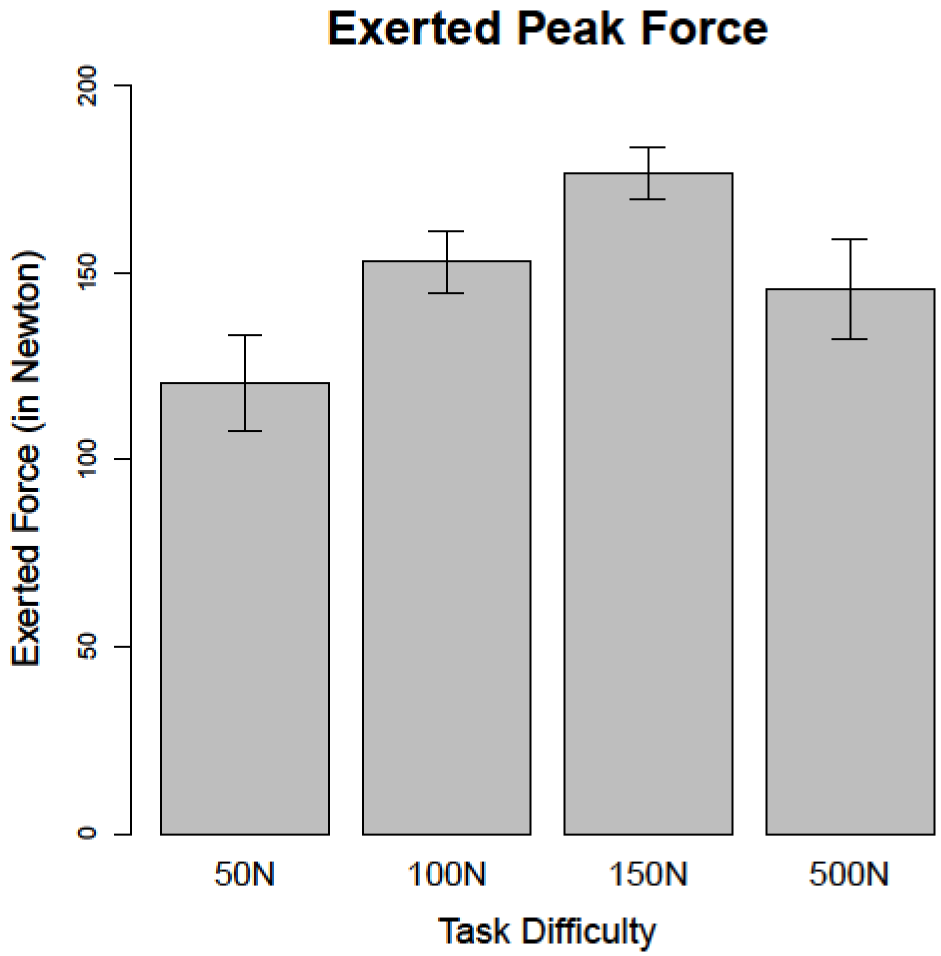

Figure 2. Means of exerted peak force (in Newton) during the fifth block of the task in Study 2. Error bars represent standard errors.

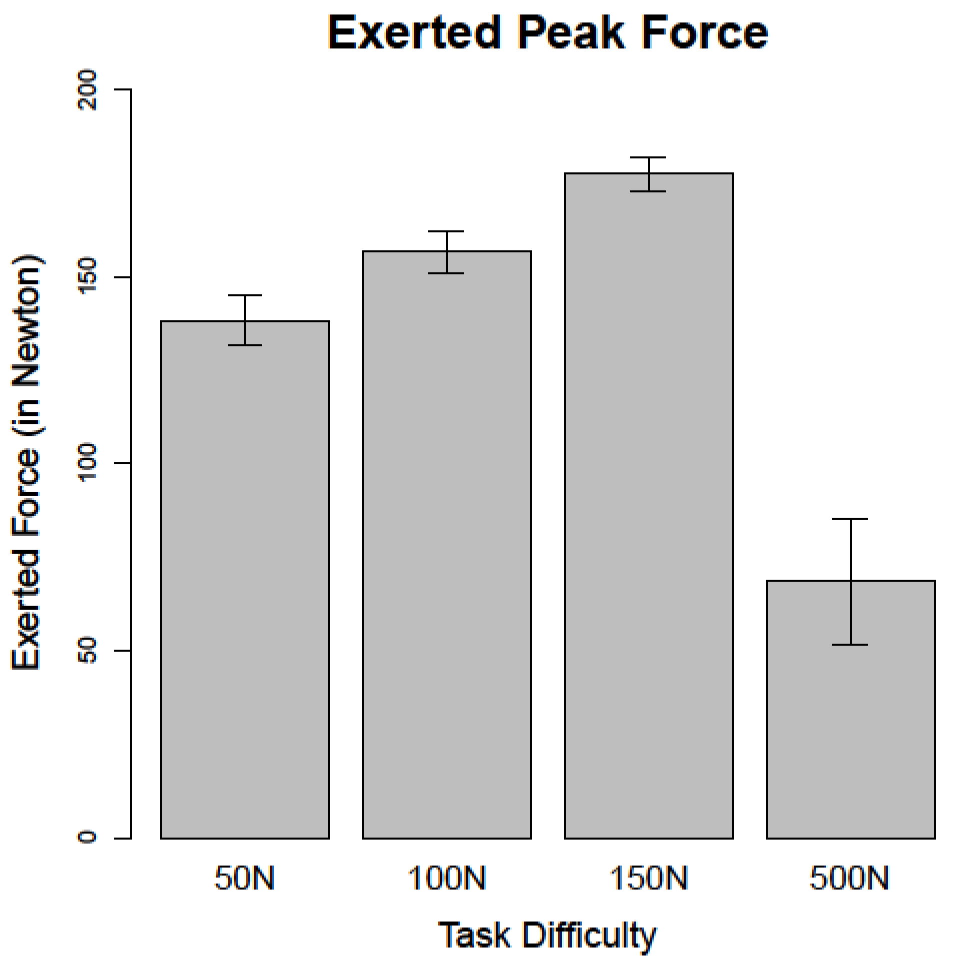

Figure 3. Means of exerted peak force (in Newton) during the fifth block of the task in Study 3. Error bars represent standard errors.

Table 1

Studies and Disengagement Conditions Included in the Meta-analysis

Article	Study	Included Disengagement Conditions
Barreto, Wong, Estes, & Wright (2012)	1	Women-difficult-task
Barreto, Wright, Krubinski, Molzof, & Hur (2015)	1	All conditions except the men-masculine-incentive-difficult-task and the women-feminine-incentive-difficult-task conditions
Brinkmann & Gendolla (2008)	1	Dysphoria-difficult-task
Brinkmann & Gendolla (2008)	2	Dysphoria-difficult-task
Chatelain, Silvestrini, & Gendolla (2016)	1	Fear-prime-difficult-task
Freydefont & Gendolla (2012)	1	Low-incentive-sadness-primes
Freydefont, Gendolla, & Silvestrini (2012)	1	Sadness-prime-difficult-task
Gendolla (1998)	1	Identity-irrelevant-difficult-task
Gendolla (1999)	1	Self-irrelevant-very-difficult-task
Gendolla & Krüsken (2001)	1	Negative-mood-difficult-task
Gendolla & Krüsken (2002a)	1	Negative-mood-difficult-task, negative-mood-extremely-difficult-task, positive-mood-extremely-difficult-task
Gendolla & Krüsken (2002b)	1	Negative-mood-non-contingent-consequence-difficult-task
Gendolla & Krüsken (2002b)	2	Negative-mood-non-contingent-consequence-difficult-task
Gendolla & Richter (2006a)	1	No-social-observation-difficult task
Gendolla & Richter (2006b)	2	Low-ego-involvement-extremely-difficult-task, high-ego-involvement-extremely-difficult-task
Gendolla, Richter, & Silvia (2008)	2	Low-self-focus-difficult-task, low-self-focus-extremely-difficult, high-self-

(continued)

		focus-extremely-difficult
Lasauskaite Schüpbach, Gendolla, & Silvestrini (2014)	1	Suboptimal-prime-sadness-prime-difficult-task-
Richter, Baeriswyl, & Roets (2012)	1	Low-NFC-difficult-task
Richter, Friedrich, & Gendolla (2008)	1	Impossible-difficulty
Richter & Gendolla (2006)	2	Clear-difficulty-no-reward, clear-difficulty-reward
Silvestrini (2015)	1	Pain-prime-moderate-incentive
Silvestrini & Gendolla (2009)	1	Negative-incentive-negative-mood-difficult-task
Silvestrini & Gendolla (2011a)	1	Sad-primes-difficult-task
Silvestrini & Gendolla (2011b)	1	Low-instrumentality-negative-mood

(continued)

Article	Study	Included Disengagement Conditions
Silvestrini & Gendolla (2013)	1	Action-prime-extremely-difficult, inaction-prime-extremely-difficult
Silvestrini & Gendolla (2013)	2	Action-prime-low-incentive, inaction-prime-low-incentive
Silvia (2012)	2	Control-high-difficulty
Silvia (2012)	3	Control-high-difficulty
Silvia, Kelly, Zibaie, Nardello, & Moore (2013)	1	Control-priming-hard-primes
Silvia, McCord, & Gendolla (2010)	1	Low-self-focus-hard-task
Wright, Contrada, & Patane (1986)	1	Extremely-difficult-task
Wright & Dismukes (1995)	1	Low-ability-difficult-task
Wright & Gregorich (1989)	1	Low-probability-moderately-difficult-task
Wright et al. (2007)	1	High-fatigue-relevance-low-task-B-difficulty
Wright et al. (2007)	2	All conditions except the low-fatigue-relevance-high-task-B-difficulty condition
Wright & Lockard (2006)	1	Women-low-expectancy, men-low-expectancy

Wright, Martin, & Bland (2003)	1	Task-A-difficult-task-B-difficult

(continued)

Article	Study	Included Disengagement Conditions
Wright, Murray, Storey, & Williams (1997)	1	Female-participant-high-standard masculine-task, male-participant-high-standard-feminine-task
Wright, Murray, Storey, & Williams (1997)	2	All conditions except the female-participant-high-standard-feminine-task and the male-participant-high-standard-masculine-task conditions
Wright, Shaw, & Jones (1990)	1	Low-noise-difficult-task

Note. The condition labels correspond to the labels used in the original articles.