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Frequency estimation and semantic ambiguity do not eliminate conjunction bias, when it occurs: Replication and extension of Mellers, Hertwig, and Kahneman (2001)

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Mellers, Hertwig, and Kahneman (2001) conducted an adversarial collaboration to try and resolve Hertwig's contested view that frequency formats eliminate conjunction effects, and that conjunction effects are largely due to semantic ambiguity. We conducted a pre-registered well-powered very close replication (N = 1032), testing two personality profiles (Linda and James) in a four conditions between-subject design comparing unlikely and likely items to "and" and "and are" conjunctions. Linda profile findings were in support of conjunction effect and consistent with Tversky and Kahneman's (1983) arguments for a representative heuristic. We found no support for semantic ambiguity. Findings for James profile were a likely failed replication, with no conjunction effect. We provided additional tests addressing possible reasons, in line with later literature suggesting conjunction effects may be context-sensitive. We discuss implications for research on conjunction effect, and call for further well-powered pre-registered replications and extensions of classic findings in judgment and decision-making.

Keywords: conjunction effect, frequency estimation, replication, Linda problem, judgment and decision making

The conjunction fallacy is one of the most well-known judgment errors in the judgment and decision making (JDM) literature. The fallacy consists of judging the conjunction of two events as more likely the any of the two specific events, violating one of the most fundamental tenets of probability theory that postulates that probability of a conjunction of two events can never be higher than the probability any of the two individual events.

Kahneman and colleagues initially reported the conjunction effect as a bias, and that resulted in an intense debate in the academic community (e.g.,

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Fiedler, 1988; Gigerenzer, 1996, 2005; Hertwig & Chase, 1998; Hertwig & Gigerenzer, 1999). One view opposing conjunction effect as a bias was by Hertwig and colleagues that argued that conjunction effect is not at all a fallacy, demonstrating that the effect arises out of semantic ambiguity, in that participants' understanding of natural language words such as "probability" and "and" diverged from that of experimenters (e.g., Hertwig & Gigerenzer, 1999). Daniel Kahneman and Ralph Hertwig engaged in an adversarial collaboration to which Barbara Mellers served as an arbiter. They all then jointly examined the potential semantic ambiguity of "and" conjunction to try and explain the conjunction effect reported in the Kahneman and Tversky's study (1996). The article has been influential with over 430 citations according to Google Scholar at the time of writing.

Chosen study for replication: Outline of Mellers et al (2001)

Mellers et al. (2001) conducted examined frequency estimates of personality sketches. They tested two personality sketches in three experiments, one about Linda and the other about James. For example, the Linda story read as:

> *Linda is 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations.*

Participants read the scenario and estimated how many of a 100 people like Linda fit a particular target description. The target descriptions varied between experimental conditions: likely (feminists), unlikely (bank tellers), semantic "and" (bank tellers and feminists), and semantic "and are'" (bank tellers and are feminists). Kahneman argued that the conjunction effect would occur despite frequency estimation was used, reflected from the average frequency estimates of the conjunction conditions "and" and "and are" higher than the unlikely item condition. Hertwig proposed that conjunction phrase "bank teller and are feminists" would not yield support for conjunction effects. The results for the Linda scenario supported Kahneman's prediction across two out of three experiments conducted as part of the adversarial collaboration, whereas, with the James scenario just one experiment supported the prediction.

We summarized findings in the original article in Table 1. The divergence of findings reported across the three experiments made it hard for readers to assess the overall effect size, and we, therefore, conducted a mini meta-analysis summary of their effects across experiments, summarized in Table 2.

The need for replication

Since the first demonstration of the conjunction effect, there have been attempts to develop a theory to explain the phenomenon. Semantic ambiguity remains the strongest counterargument to the demonstration of conjunction effects. With the recent growing recognition of the importance of reproducibility and replicability in psychological science (e.g., Brandt et al., 2014; Open Science collaboration, 2015; van't Veer & Giner-Sorolla, 2016; Zwaan, Etz, Lucas, & Donnellan, 2018), we felt it was important to establish the replicability of the findings noted in the Mellers et al. (2001).

We, therefore, embarked on a well-powered preregistered very close replication of Mellers et al. (2001) employing the most current psychological science methods, which would allow to test for both the presence and possible absence of an effect.

Present investigation

We had several goals. First, we set out to revisit the original experimental design and assess the replicability of the original findings. With power analyses and higher power, we aimed at detecting weak effects that may not have been possible in the original study. Secondly, we complemented the traditional analyses in the original article with equivalence tests and Bayesian analyses to also allow for quantifying evidence in support of the null hypothesis. Third, we added extensions to examine further lay perceptions of provided statistical information that may explain some of the differences found in the original findings.

Table 1

Summary of findings in Mellers et al. (2001) Experiments 1 to 3 and the replication

		Linda story				James story				
	Target	Exp1	Exp2	Exp3	Replication	Target	Exp1	Exp2	Exp3	Replication
Likely target	Feminists	58.1 (2.4)	47.7 (3.4)	47.9 (4.5)	58.43 (1.79)	Artists	41.0 (2.7)	45.1 (2.6)	47.1 (3.3)	36.2 (1.62)
Unlikely target	Bank tellers	24.6 (1.9)	21.4 (2.0)	14.3 (2.9)	9.87 (0.88)	Republi-cans	28.9 (2.1)	19.8 (1.8)	12.7 (2.6)	18.38 (1.18)
"and"	"and"	**39.9 (2.0)**	**30.4 (2.3)**	**26.4 (3.9)**	**18.8 (1.36)**	"and"	33.1 (1.8)	**42.7 (2.4)**	**22.9 (3.4)**	15.19 (1.15)
"and are"	"and are"	**40.2 (2.7)**	21.8 (2.1)	**22.8 (2.7)**	**19.55 (1.48)**	"and are"	32.0 (2.5)	20.0 (1.9)	**21.4 (2.7)**	15.55 (1.09)

Note. Exp1/Exp2/Exp3 = Experiment 1, 2, and 3. Standard errors are in the parentheses. Boldface indicates significant results, p <.05.

Table 2

Summary of findings of the original study versus replication

	Original results	Replication		
Comparison	Cohen's d with 95% CI	T-statistic (one-sided)	Cohen's d with 95% CI	Replication summary
Linda Story				
"and" and Unlikely target	0.59 [0.36, 0.82]	$t(431.26) = 5.51$, $p < .001$	0.49 [0.31, 0.67]	Signal - consistent
"and are" and Unlikely target	0.38 [-0.02, 0.77]	$t(419.21) = 5.63$, $p < .001$	0.50 [0.32, 0.67]	Signal - consistent
"and" and "and are"	0.18 [-0.09, 0.45]	$t(505.55) = -0.37$, $p = .646$	-0.03 [-0.21, 0.14]	No signal-inconsistent (opposite)
James Story				
"and" and Unlikely target	0.62 [0.08, 1.15]	$t(507.82) = -1.93$, $p = .973$	-0.17 [-0.35, 0.00]	Signal-inconsistent (opposite)
"and are" and Unlikely target	0.17 [-0.07, 0.41]	$t(510.69) = -1.76$, $p = .960$	-0.15 [-0.33, 0.02]	No signal-inconsistent (opposite)
"and" and "and are"	0.41 [-0.26, 1.08]	$t(506.05) = -0.23$, $p = .591$	-0.02 [-0.19, 0.15]	No signal-inconsistent (opposite)

Note. Linda story can be concluded as a successful replication. James replication is a likely failed replication. In addition, there was no support found for semantic ambiguity (comparing "and" and "and are"). In the original article, effect sizes (ES) were not reported; we computed Cohen's d and confidence intervals based on the mean estimates and standard errors of the mean estimates of the outcome variables of the original study (see full tables in supplementary). The effect sizes of the original study presented in the table are based on the mini-meta-analysis of Experiment 1, 2, and 3 of Mellers et al. (2001), as the study is closest for direct comparison for replication summary. The replication summary directly based on LeBel et al., (2019) category, see details in "evaluation criteria for replication design and findings".

Context: Large replication effort of judgement and decision-making findings

The current replication was part of a large-scale pre-registered replication project aiming to revisit well-known research findings in the area of judgment and decision making (JDM) and to examine the reproducibility and replicability of these findings. In this project, all replications are conducted by students in undergraduate courses and undergraduate and masters guided thesis at the University of Hong Kong psychology department. Four students in two separate courses were randomly assigned to the current replication. Working independently, the students conducted an in-depth analysis of the target article, wrote pre-registrations with power-analyses, conducted data analysis on the collected data, and then wrote manuscripts for journal submission. In each student pair, students conducted peer review on one another to optimize design and analysis. A teaching assistant (6th author) and the corresponding author supervised and gave feedback in each step of the replication process. The corresponding author conducted all pre-registrations on the OSF and online data collection. More information on the process is provided in the supplementary, and further details and updates on this project can be found on: https://osf.io/5z4a8/ (CORE, 2020).

Method

Pre-registration, power analysis, and open-science

We pre-registered the experiment on the Open Science Framework (OSF), and data collection was launched later that week. Pre-registration with power analyses and all materials used in the study are available in the supplementary materials. All measures, manipulations, and exclusions are reported, and data collection was completed before analyses. OSF pre-registration review link for the study: https://osf.io/gb7pk. Data and R/RMarkdown code (R Core Team, 2015) is available on the OSF: https://osf.io/6v8e2/. Full open-science details and disclosures are provided in the supplementary. Please note the pre-registration crowdsourcing process involved four students who worked independently to analyze the original article, document hypotheses and tests in the original study, propose analyses for testing predictions, calculate original effects, conduct a power-analysis, and propose extensions. We note the differences and similarities across four pre-registration documents in the supplementary materials (for details see Table S12-S14), and we followed the combination of all of those in our analyses.

We aimed to detect smallest the effect size of d = 0.20 at a power of 0.80 one-tail comparing two conditions, despite the reported effects in the target article and original findings being much higher. This was meant to allow us the possibility of detecting effects not found in the target article for one of the two scenarios (details below).

Participants

A total of 1032 participants were recruited online through American Amazon Mechanical Turk (MTurk) using the TurkPrime.com platform (Litman, Robinson, & Abberbock, 2017) (M_{age} = 38.77, SD_{age} = 12.07; 550 females). We identified four responses to be excluded based on the exclusion criteria we recorded in the pre-registration due to their self-reported lack of seriousness or English proficiency, yet exclusions had no impact on the findings and so our main report focuses on the full sample.

Procedure

Participants were randomly assigned to one of the four experimental conditions (likely, unlikely, "and", and "and are"). All participants read two personality profiles, one of Linda and the other of James, exactly as in the original study. Each profile consisted of one short description of a character, and frequency estimation questions.

All descriptions and questions were taken from the original article (Mellers et al., 2001). The presentation order of the two profiles was randomized.
Linda profile description was as follows:

> *Linda is 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations.*
>
> *Of 100 people like Linda, how many are [likely: feminists?] [unlikely: bank tellers?*] ["and": b*ank tellers and feminists?] [“and are”: bank tellers and are feminists?*]

James profile description was as follows:

> *James grew up in a Bohemian family. His father was a musician, and his mother was a painter. They lived together for 40 years and never got married. James was a very talented child with a special gift for comedy, but he turned into a rebellious troublemaker in his youth. He dropped out of college after two years and traveled to Asia to learn crafts. James is now 35 years old.*
>
> *Of 100 people like James, how many are [likely: artists?] [unlikely: Republicans?] ["and": Republicans and artists?] ["and are" Republicans and are artists?]*

Participants answered questions based on two scenarios, one for Linda and one for James, according to their randomly assigned condition (indicated in brackets in the scenarios above). The dependent variable was the estimated frequency of the described personality in the scenario measured on a scale from 1 to 100. The supplementary details the experimental instructions, scenarios, and response variables.

Extension

Following the replication materials, participants proceeded to the next page and answered six additional questions. Depending on their assigned condition participants were asked to estimate the percentage of people, females, and males in the United States that match the target item (likely, unlikely, "and", "and are"), and they did so for both profiles. For example, participants in the likely condition estimated the percentage of people, females, and males in the United States that are 1) feminists, 2) artists.

We had several aims with this extension: 1) assess whether the conjunction effect would show for the generalized population without the specific descriptions of James and Linda, and 2) examine possible gender differences in the estimations of the items used in the James and Linda descriptions.

Data analysis plan

Our analyses matched the original article's hypotheses, as follows:

> *Hypothesis 1:* The frequency estimate for the "and" conjunction phrase will be higher than the phrase describing unlikely target alone.

Two sets of competing hypotheses suggested by Hertwig and Kahneman:

> *Hypothesis 2a:* The frequency estimate for the "and are" conjunction phrase will be higher than the phrase describing unlikely target alone.
>
> *Hypothesis 2b:* The frequency estimate for the "and are" conjunction phrase will not be higher than the phrase describing unlikely target alone.
>
> *Hypothesis 3a:* The frequency estimate for the "and are" conjunction phrase will be lower than the frequency estimate for 'and" conjunction phrase.
>
> *Hypothesis 3b:* The frequency estimate for the "and are" conjunction phrase will not be lower than the frequency estimate for 'and" conjunction phrase.

A comparison of the three experiments in the original article and the current replication is provided in Table S4 of the Supplementary Materials. In Table S5, we briefly note the reasons for the chosen differences between original studies and the replication attempt. In the replication attempt, we did not include filler items, because when filler items are present, the responses are inherently comparative and therefore drive the conjunction effect observed (Hertwig & Chase, 1998). Supporting this view, the results of both Study 1 and Study 3 of the original study that included filler items found support for conjunction effect—for both "and" and "and are" conjunction phrases. Given the possibility of different psychological processes between comparative and non-comparative responses, we excluded filler items, that allow for the test of competing predictions from Kahneman and Hertwig theorized to be essentially non-comparative in nature. More importantly, with the current focus on testing the main argument if the conjunction effects are driven by semantic ambiguity of natural language term "and" in a frequency representation.

We chose to focus on "and" and "and are" as the conjunction phrases and implement a between-subjects design which would allow for a clearer test of the competing predictions between Kahneman and Hertwig. For instance, Hertwig argued that the frequency judgments are possibly driven by the understanding that "and" is a union operator, and the use of a more restrictive "and are" phrase would take

away the conjunction effect. Kahneman argued that judgments were driven by a match between a personality description and porotype of a category; therefore, both "and" and "and are" phrases would likely yield conjunction effects.

Following the analyses in the target original, we first conducted Welch (based on recommendations of Delacre, Lakens, & Leys, 2017) one-tail independent samples t-test, a null-hypothesis significance testing (NHST) method. When NHST analyses were non-significant, we complement NHST analyses with equivalence testing to compare effects against a minimal effects considered meaningful (TOSTER package; Lakens, 2017; Lakens, Scheel, & Isager, 2018) and Bayesian analyses to quantify support for the null hypothesis given a prior (Kruschke & Liddell, 2018; Vandekerckhove, Rouder, & Kruschke, 2018) using BayesFactor R package (Version 0.9.12-4.2; Morey & Rouder, 2015). These were minor adjustments we made to the pre-registration data analysis plan, summarized in Table S6.

Evaluation criteria for replication design and findings

Table S7 provides a classification of the replications using the criteria by LeBel, McCarthy, Earp, Elson, and Vanpaemel (2018) criteria (see Figure S2). We summarize the current replication as a "very close replication".

To interpret the replication results we followed the framework by LeBel, Vanpaemel, Cheung, and Campbell (2019). They suggested a replication evaluation using three factors: (a) whether a signal was detected (i.e., confidence interval for the replication Effect size (ES) excludes zero), (b) consistency of the replication ES with the original study's ES, and (c) precision of the replication's ES estimate (see Figure S1).

Results

Descriptive statistics are detailed in Table 1 and statistical tests and effect-size findings are summarized in Table 2.

Conjunction effects

We first looked for the conjunction effect for each profile, by comparing frequency estimates for both "and" and "and are" conditions with the "unlikely" condition. Considering the Linda scenario, "and" condition (n = 252, M = 18.80, SD = 21.62) were greater than for the "unlikely" condition (n = 258, M = 9.87, SD = 14.1; M_d = 8.93, t(431.26) = 5.51, p < .001, d_s = 0.49, 95% CI [0.31, 0.67]; see Figure 1). Similarly, frequency estimates of "and are" condition (n =258, M = 19.55, SD = 23.74) were greater than "unlikely" condition (n = 258, M = 9.87, SD = 14.15; M_d = 9.69, t(419.21) = 5.63, p < .001, d_s = 0.50, 95% CI [0.32, 0.67]). Thus, results lend support toward H1 and H2a in the Linda scenario.

However, differences across conditions for the James scenario (see summary plot in Figure 1; "and" condition: n = 252, M = 15.19, SD = 18.24; "unlikely" condition: n = 258, M = 18.38, SD = 19.03; "and are" condition: n = 258, M = 15.55, SD = 17.55). The "and" versus "unlikely" contrast (M_d = −3.19, t (507.82) = −1.93, p = .973; d_s = -0.17, 95% CI [-0.35, 0.00]) show that frequency estimates for "and" condition were lower than "unlikely" condition, although the difference was not statistically significant. Therefore, the results of the James scenario failed to support H1. Similarly, the contrast between "unlikely" and "and are" conditions (M_d = −2.83, t(510.69) = −1.76, p = .960; d_s = -0.15, 95% CI [-0.33, 0.02]) show that frequency estimates for "and are" condition were lower than "unlikely" condition, though with a weak effect not statistically significant. In essence, the results support H2b.

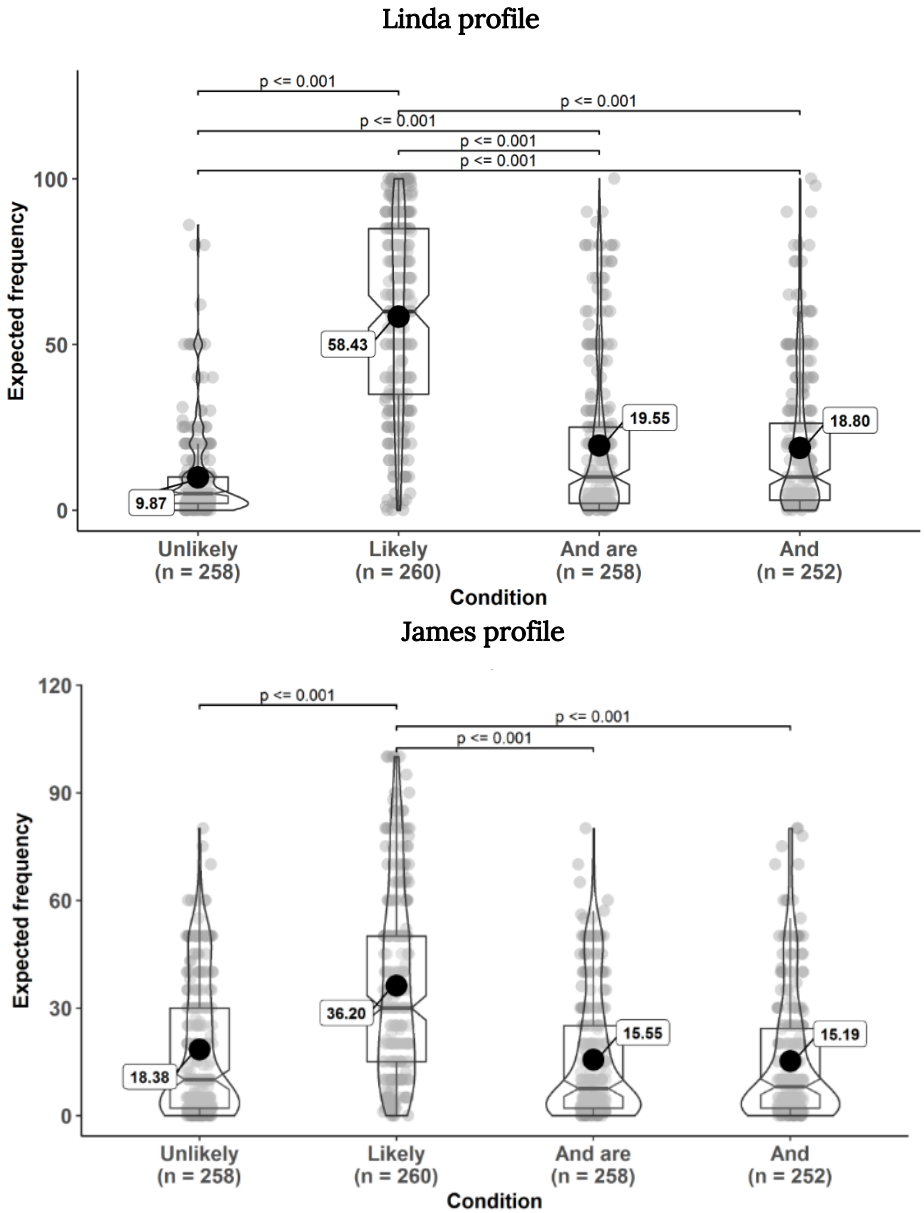
Semantic ambiguity?

To examine whether the semantically ambiguous word "and" had an effect on participants' judgment, we conducted a one-tail Welch t-test comparing frequency estimates of "and" and "and are" conditions for each of the personality scenarios. As predicted by H3a, we found no support for differences for the Linda profile (M_d = −0.75, t(505.55) = −0.37, p = .646, d_s = -0.03, 95% CI [-0.21, 0.14]) or for the James profile (M_d = -0.36, t(506.05) = -0.23, p = .591, d_s = -0.02, 95% CI [-0.19, 0.15]).

Next, we conducted an equivalence test of the semantic ambiguity effect. Based on Simonsohn's (2015) recommendation for replication studies we calculated the smallest effect size of interest (SESOI) that Mellers et al.'s experiment could have detected with a power of 33%. We choose Experiment 2 of as a reference for equivalence test analysis based on one important similarity between the Experiment 2

Figure 1

Linda and James profiles: violin plots for expected frequency of target item.



Note. Boxes represent interquartile range of the distribution, with the notch in the middle representing the mean. The density of the violin plots represents the density of the data at each value, with wider sections indicating higher density. Note that the p-values for the contrast effects are for two-tail tests, different from the one-tail tests. Plots were generated using ggstatsplot R package (Patil, 2018).

and the current replication. That is, both studies did not include filler items. With an *N* of 96 in each condition, Mellers et al. (2001) had 33% power to detect an effect size of $d = 0.22$. We used it as the equivalence bound for the Study (SESOI set to $d = 0.22$). Equivalence tests for both Linda story ($t(505.55) = -2.11$, $p = .018$) and James story ($t(506.05) = -2.25$, $p = .012$) indicating support for the null, meaningfully smaller from SESOI.

Furthermore, we conducted one-tail Bayesian *t*-tests with a prior set at 0.707 with a null region of (0, ∞) such that the results against null (i.e., against mu = 0) would quantify support the semantic ambiguity hypothesis suggested by Hertwig and colleagues. For the Linda profile, we found $BF_{10} = 0.08$ (or $BF_{01} = 13.32$), which indicates that, given the data, the null-hypothesis is over 11 times more likely than the one-sided alternative. Similarly, for the James profile, $BF_{10} = 0.08$ (or $BF_{01} = 12.06$), which indicates that given data, the null-hypothesis is over nine times more likely than the one-sided alternative.

Additional analyses

The James profile may have been less representative of an artist in comparison to the Linda profile as representative of a feminist. To test this aspect, we compared the average frequency estimations for James and Linda story within 'likely' experimental condition, in which participants rated the extent to which Linda and James were representative of a feminist and an artist, respectively. Frequency estimations for the "likely" condition for Linda profile ("feminists", $n = 260$, $M = 58.43$, $SD = 28.93$) were greater than for James profile ("artists", $M = 36.20$, $SD = 26.08$; $M_d = 22.22$, $t(259) = 11.99$, $p < .001$, $d_s = 0.81$, 95% CI [0.61, 0.88]). Whereas, a similar comparison between Linda and James story within the unlikely condition show that frequency estimate for Linda ("Bank teller", $n = 258$, $M = 9.87$, $SD = 14.15$) was lower than James ("Republicans", $M = 18.38$, $SD = 19.03$; $M_d = -8.52$, $t(257) = -6.87$, $p < .001$, $d = -0.50$, 95% CI [-0.56, -0.30]). This pattern of the observed difference between Linda and James across "likely" and "unlikely" conditions is consistent with the previous work that found that the occurrence of conjunction effects, for example, depends on the probabilities of A (*Linda is a bank teller)* and B (*Linda is active in the feminist movement*). In particular, there is a higher chance of conjunction effect when people perceive lower the probability of the less probable constituent P(A), and P(B) was high, in comparison to cases where P(A) and P(B) were both low or both high (Fisk & Pidgeon, 1996; Wells, 1985).

The study included additional variables that mirrored the outcome variables but asked the participants to rate the percentage of males and females in the population that fit the description. For example, participants in 'and' condition after reading Linda story answered "Try and estimate, what percentage of females in the U.S. are Bank Tellers and Feminists?", and after reading James story answered "Try and estimate, what percentage of males in the U.S. are Republicans and Artists?". We looked at the contrasts between the outcome variables and these additional variables across experimental conditions to ascertain if the ratings on the outcome variable were driven by profile description, rather than Linda by virtue of the name being female and similarly James being male. For Linda story across three experimental conditions Linda was rated higher on the outcome variable in comparison to the percentage of females in society (likely condition: $M_d = 15.31$; $t(259) = 8.67$, $p < .001$; $d = 0.58$, 95% CI [0.41, 0.67]; 'and' condition: $M_d = 6.43$; $t(251) = 4.75$, $p < .001$; $d = 0.32$, 95% CI [0.17, 0.43]; 'and are' condition: $M_d = 5.79$; $t(257) = 3.98$, $p < .001$; $d = 0.27$, CI [0.12, 0.37]). Similarly, for the James story, across conditions we found that James was rated higher on the outcome variable in comparison to the percentage of males in society (likely condition: $M_d = 19.10$; $t(259) = 11.15$, $p < .001$; $d = 0.87$, CI [0.56, 0.83]; 'and' condition: $M_d = 3.81$; $t(251) = 3.36$, $p = .001$; $d = 0.23$, 95% CI [0.09, 0.34]; 'and are' condition: $M_d = 2.58$; $t(257) = 2.39$, $p = .018$; $d = 0.15$, 95% CI [0.03, 0.27]).

Summary of replication findings

The evaluation of the replication findings is summarized in Table 2. Our replication for the Linda profile was in support of the confirmatory predictions based on the conjunction effects. Whereas the results for the James profile were inconsistent. Importantly, the original study reported that in frequency estimate for "and" condition is higher than Unlikely condition. This prediction forms the basis for testing the absence or presence of semantic ambiguity in predicting the conjunction effects. The replication results for this prediction are in the opposite direction, i.e., we found frequency estimates were lower for Unlikely condition than "and" condition. Therefore, the results of the James scenario are inconclusive in teasing apart the semantic ambiguity associated with "and" conjunction term.

Extension

Descriptive results for the extension are provided in Table S8, and plots are provided in Figures S3 to S6.

We first tested whether the conjunction effect occurred for any of the three items (people, male, females; within design) for each of the profiles (Linda and James, between design) and their assigned condition (likely, unlikely, "and", "and are"). As expected, we found no support for a conjunction effect for general population females with the Linda profile items (feminist and bank teller) yet without the Linda description. Similarly, we found no effect for males with the general population James profile items (Republicans and artist) yet without the James description. These findings should be interpreted with caution, yet these are in support of the conjunction effect demonstrated with the Linda and James problems as being affected by the description of Linda and James in a way that makes conjunction items more salient than the unlikely. Meaning, that the conjunction effect may be dependent on the representativeness heuristic (Tversky & Kahneman, 1982) and the preceding described profile.

Yet, we found support for a conjunction effect for the Linda items for the estimation of people overall (feminist: $M = 29.36$, $SD = 17.13$; bank teller: $M = 8.56$, $SD = 12.2$; "and": $M = 11.01$, $SD = 14.01$). It remains to be explored why there would be support for a conjunction effect for evaluation of people overall, but not for females or males, yet it does point out that the conjunction effect may sometimes occur without the representativeness heuristic description, and with a within-subject design. At the very least, this suggests that the conjunction effect is context-sensitive, as is also indicated in the differences in effects we found between the Linda and the James problem.

There were also patterns indicating statistical flaws, such that given a population gender split of 50%-50% for females-males, participants indicated means for the general population that were far from the average of the estimation for females and the estimation of males (e.g., people who are bank teller: $M = 8.56$, $SD = 12.2$; females who are bank tellers: $M = 21.46$, $SD = 28.64$; males who are bank tellers: $M = 9.93$, $SD = 15.40$). This is despite the within-subject design and the three questions being presented together. If participants indeed understood these questions correctly, this may be indicative of elicitation of estimate separately for each of the questions irrespective of the context or priors, and/or an inability to process or report percentages.

Further findings regarding gender effects for the items in the two profile is provided in Tables S10 and S11.

Discussion

We conducted a preregistered well-powered replication of the main design across the three studies of Mellers et al.'s (2001).

Our findings regarding the Linda profile demonstrate support for conjunction effects for both "and" and "and are" connectors. The findings of the Linda scenario are not supportive of the alternative view that that conjunction effects observed in the Linda story are a manifestation of semantic interpretation of "and" term by participants as union instead of the intersection. The semantic ambiguity arguments predicted that "and are" experimental condition will fail to provide support for conjunction effects, and participants' frequency estimate in "and are" experimental condition will be lower than "and" experimental condition. Furthermore, in reference to Linda story, we compared if the frequency estimates in the "and are" condition was lower than "and" condition. Equivalence testing and Bayesian analyses indicated support for null differences. These findings are in support of the Kahneman view of conjunction effects with frequency estimates.

Our findings for the James profile were not in support of either the Kahneman or the Hertwig hypotheses and previous findings. Firstly, the comparison between "and" and "unlikely" condition was not in support of a conjunction effect. Secondly, we found no support for differences between frequency estimates between "and are" an unlikely condition. Further, similar to Linda story the planned comparison that tested if the frequency estimates in the "and are" condition was lower than "and" condition supports the view that differences between conditions were statistically equivalent to zero. Failure to find empirical support for conjunction effects with James story suggests that conjunction effects are context specific. Conjunction effects are commonly demonstrated using the Linda profile, yet the findings regarding other scenarios are less clear (Costello & Watts, 2017). Thus, it is quite possible that James and Linda scenarios are qualitatively different.

A closer examination of the original findings showed that the effects of the James scenario varied considerably across the experiments from weak effects in Experiment 1 ("and" and unlikely: d = 0.21; "and are" and unlikely: d = 0.13) with no indication of semantic ambiguity (d = 0.05) to mixed effects in Experiment 2 ("and" and unlikely: d = 1.11; "and are" and unlikely: d = 0.01) indicating strong semantic ambiguity effect (d = 1.08). The mini meta-analytic effect we computed for the three original studies seemed to indicate differences in effect size between the Linda and the James scenarios, especially in regards to semantic ambiguity.

Additional analyses we conducted suggested that the personality sketch of James was less representative of an artist in comparison to Linda's personality sketch of a feminist. The observed difference is consistent with view Kahneman's argument that conjunction effects arises through the substitution of representativeness estimates for probability estimates. This may have been one of the reasons why the current study does not find support for conjunction effect for James story even when then comparison was between the unlikely and the "and" conditions, which was supported in Study 2 and 3 of the original paper.

The current replication effort supports the Tversky and Kahneman's (1983) assertion that conjunction effects, when those occur, are a probabilistic error due to representativeness and availability heuristic. More precisely, the results of the current study for Linda story are supportive of the view that frequency estimates do produce conjunction effects that rely on judgmental heuristic and are not driven by semantic ambiguity of the conjunction terms. The results for the James profile were inconclusive to likely failure.

Overall, we found some support for conjunction effects, but that those may be less robust than initially expected. These findings indicate the importance of further conducting well-powered preregistered replications and extensions that would revisit classic experiments in this domain and aim to gain deeper insights of effect, to investigate the reliability and generalizability of previous findings, the contextual variations of the conjunction effect.

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Author Contributions

Gilad Feldman (GF) was the course instructor for two social psychology courses (PSYC2071/3052) and led the two reported replication efforts in these courses. GF supervised each step in the project, conducted the pre-registrations, and ran data collection. Subramanya Prasad Chandrashekar (SPC) integrated the two replication efforts into a manuscript with validation and further extensions of the statistical analyses. GF and SPC jointly finalized the manuscript for submission.

Yat Hin Cheng and Chi Long Fong worked on the replication as part of the Judgment and Decision Making course (identified as Students PSYC2071 in the table below). Ying Chit Leung and Yui Tung Wong worked on the replication as part of the advanced social psychology course (identified as Students PSYC3052 in the table below).

Contributor Roles Taxonomy

In the table below, employ CRediT (Contributor Roles Taxonomy) to identify the contribution and roles played by the contributors in the current replication effort. Please refer to the url (https://www.casrai.org/credit.html) on details and definitions of each of the roles listed below.

Role	SPC	GF	Students PSYC 2071	Students PSYC 3052	TA
Conceptualization		X			
Pre-registrations		X	X	X	
Data curation		X			
Formal analysis	X	X	X	X	
Funding acquisition		X			
Investigation		X	X	X	
Methodology		X		X	
Pre-registration peer review/ verification	X		X	X	X
Data analysis peer review/ verification	X		X	X	
Project administration		X			X
Resources		X			
Software	X	X	X	X	
Supervision					X
Validation	X	X			
Visualization	X				
Writing-original draft	X	X			
Writing-review and editing	X	X			

Open Science Practices

This article earned the Preregistration+, Open Data and the Open Materials badge for preregistering the hypothesis and analysis before data collection, and for making the data and materials openly available. It has been verified that the analysis reproduced the results presented in the article. The editorial process for this article relied on streamlined peer review where peer reviews obtained from previous journal(s) were moved forward and used as the basis for the editorial decision. These reviews are shared in the supplementary files, in the authors' cover letter. The identities of the reviewers are shown or hidden in accordance with the policy of the journal that originally obtained them. The entire editorial process is published in the online supplement.

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