**Reliability Assessment of Self-Prioritization Effect as Measured by the Perceptual Matching Task**

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***Abstract:***

Recent years have witnessed a growing focus on the reliablity of cognitive tasks, driven in part by the reliability paradox. This paradox stems from the observation that while cognitive tasks yield consistent experimental effects, they do not exhibit the same reliability when assessing individual differences. Here we investigate the reliability of the Self Perceptual Matching Task (SPMT), a widely used tool for investigating the cognitive processes underlying the self-prioritization effect (SPE), a effect that people perform better when stimuli are associated to the self than when they are to others. In this preregistered study, we evaluated the reliability of 24 SPE measures from seventeen datasets (N = 805), all utilizing the SPMT. We calculated Monte-Carlo based split-half reliability (r) and intraclass correlation coefficient (ICC2) for each SPE measure. Our findings revealed a robust group-level SPE effect across datasets. However, when it comes to individual differences, SPE measures derived from reaction times (RT) and Efficiency exhibited relatively higher but still unsatisfied split-half reliability (approximately 0.6), compared to other SPE measures. Similarly, for the reliability across multiple time points, as assessed by ICC2, RT and Efficiency demonstrated a low level of test-retest reliability (close to 0.5). These outcomes uncover the presence of a reliability paradox in the context of SPMT-based SPE assessments. While nearly all the measures of SPE displayed robust experimental effects, their reliability are low as a measurement of individual differences. We discussed the implications of the current study for future SPE studies.

***Keywords*:** Self-Prioritization Effect (SPE), Self-Perceptual Matching Task (SPMT), Reliability, Multiverse

**1 Introduction**

The self-prioritization effect (SPE) reflects individuals' biased responses towards self-related information in comparison to that related to others. This effect has been found in a broad range of cognitive tasks. This phenomenon, documented in 1950s (Cherry, 1953), holding a central position within cognitive psychology and underscoring a core facet of human cognition and self-awareness (Sui & Humphreys, 2017). Despite SPE is often argued to be a self-specific effect, it has been challenging to be disassociated from familiarity effect. That is, the self-related stimuli, such as own objects, own faces (Keenan et al., 2000; Kircher et al., 2000; Turk et al., 2002), own voices (Hughes & Harrison, 2013; Payne et al., 2021), or own names (Constable, Rajsic, et al., 2019) are usually more familiar to participants than those other-related stimuli. To overcome such limitation, Sui et al. (2012) introduced the Self-Perceptual Matching Task (SPMT), where the self-relatedness (and other-relatedness) is acquired in the lab. In this task, participants first associate geometric shapes with person labels (e.g., circle = you, triangle = best friend, square = stranger) and then perform a matching task, judging whether a shape-label pair presented on the screen match the acquired relationship. A typical pattern from this task is that shapes associated to the self enjoy an advantage over shapes related to others. This SPE from SPMT was subsequently observed by many researchers (Constable, Elekes, et al., 2019; Golubickis et al., 2020; Golubickis et al., 2017; Hu et al., 2020), highlighting the robustness of the effect.

The reliability of SPE as measured by SPMT, however, has not been examined. Here, reliability of a cognitive tasks refers to its consistency and dependability in producing consistent results for the same person across sessions or times (Parsons et al., 2019; Zorowitz & Niv, 2023). One commonly method to assess reliability is the split-half reliability, where a test or measurement is divided into two halves, and the correlation between the two halves is calculated. A high correlation suggests that the test is internally consistent and measures the same construct reliably (Pronk et al., 2022). Another widely used method is the test-retest reliability, which refers to the extent to which a measurement or assessment tool produces consistent and stable results over time when administered to the same group of individuals under identical conditions (Kline, 2015). Both methods are from classical test theory in psychometrics (Borsboom, 2005), but less known to experimental psychologists. In experimental research, researchers usually focus on robustness of experimental effects. Robustness, in this context, pertains to the extent to which a cognitive task consistently produces the same effect at the group level across various independent participant samples. For example, the "group effect" in the Stop-Signal Task refer to differences in reaction times between different stop signal delays (Hedge, Powell, & Sumner, 2018). An effect is considered robust if these differences can be consistently observed in different samples performing the stop-signal task.

In recent years, driven by a growing interest in employing cognitive tasks to assess individual differences, researchers have turned their attention to evaluating the reliability of cognitive tasks (Karvelis et al., 2023). However, existing findings have raised concerns about the reliability of many cognitive tasks. (Hedge, Powell, & Sumner, 2018). A considerable body of research has highlighted the moderate to low level reliability found in the cognitive task measurements (Clark et al., 2022; Enkavi et al., 2019; Green et al., 2016). For instance, Hedge et al. (2018) report a range of test-retest reliabilities pertaining to frequently employed experimental task metrics (such as Stroop and Stop-Signal Task), with a notable prevalence of discrepancy between the low reliability for individual differences and the robustness of the experimental effects. This discrepancy, named as "reliability paradox" (Logie et al., 1996), had gain much attention in recent years (Hedge, Powell, Bompas, et al., 2018; Hedge, Powell, & Sumner, 2018). As other cognitive tasks, SPMT is also employed by researchers as a measure of individual diffrences in SPE. For example, a recent study examine the individual difference of SPE and how these individual differences are correlated to brain network (Zhang et al., 2023). Likewise, in clinical investigation, the SPMT has been incorporated to assess deviations in self-processing among specific populations, including individuals affected by autism or depression (Hobbs et al., 2023; Liu et al., 2022). This trend calls for assessing the reliability of SPMT as a measurement of SPE.

Further, the varibilities in quantifying SPE call for a comphensive examination of the relability of different SPE measures. As simple as the SPMT, there are multiple approaches to quantify the SPE, encompassing various indicators and baselines. In a typical SPMT experiment, two direct outcomes are generated: reaction times (RTs) and choices. The mean RTs and accuracy are two most widely used indicators of SPE. Several indicators can be derived from reaction times and choice: efficiency (*η*) (Humphreys & Sui, 2015; Stoeber & Eysenck, 2008), sensitivity score (*d’*) under signal detection theory (Hu et al., 2020; Sui et al., 2012), and drift rate (*v*) and starting point (*z*) estimated using the drift-diffusion models (DDM) (Golubickis et al., 2017). In addition to the variability of indicators, SPE can be estimated by calculating the difference between self condition with different baselines. Indeed, the selection of baselines varies across studies, including “Close other” (e.g., Friend) (Navon & Makovski, 2021; Svensson et al., 2022)), “Stranger” (Constable et al., 2021; Orellana-Corrales et al.), “Celebrity” (e.g., “LuXun”) (Qian et al., 2020), and “Non-person” (e.g., None)) (Schäfer & Frings, 2019). To summaries, two pivotal questions related to SPMT remain unresolved: (1) given the variability of indicators (RT, ACC, *d’, η, v, z*) and choice of baseline conditions ("Close other”, “Stranger”, “Celebrity”, and “Non-person”), which way of quantifying SPE is the most reliable one(s)? (2) Is the SPE measured by SPMT suitable for assessing individual differences? Addressing these questions is crucial for establishing the reliability of SPMT measurements, allowing for accurate assessment of the SPE and its implications in various domains.

To address these two questions, the present study investigated the reliability of SPE measures computed using different outcome variables under various baseline conditions in the SPMT. This was achieved by re-analyzed 17 independent datasets (N = 805) from 9 papers and 2 unpublished projects that employees SPMT. In order to comprehensively assess the SPE measures derived from SPMT, we examined six indicators (RT, ACC, *d’*, *η*, *v*, *z*) under four baseline conditions (“Close other”, “Stranger”, “Celebrity”, and “Non-person”). We first assessed the experimental effect of theses SPE measures using meta-analytical assessments. Given the methods available for evaluating the reliability of cognitive tasks, we examine the individual level consistency via permutation-based Split-Half Reliability (r), and consistency of task performance over time using Intraclass Correlation Coefficient (ICC2, Two-way random effect model). The findings of our study provide valuable insights into the reliability of SPMT and its outcome variables, having the potential to facilitate the future utilization of SPMT in research, clinical settings, and personal performance monitoring.

# **2 Methods**

## 2.1 Ethics information

As this study is a secondary analysis of pre-existing data sourced from publicly available datasets or archived data previously collected by the author's group, informed consent and confidentiality are not applicable.

## 2.2 Experimental Design

The original SPMT used a 2 by 3 within-subject design. The first independent variable, labeled “Matching,” consisted of two levels: “Matching” and “Nonmatching,” indicating whether the shape and label were congruent. The second independent variable, labeled “Identity”, comprised three levels: “Self”, “Friend”, and “Stranger”, representing the corresponding identity associated with the shape.

Here we provided a detailed overview of the original experimental design of SPMT, as described in the Experiment 1 by Sui et al. (2012). The original SPMT consisted of two stages (refer to Fig. 1). In the first instruction stage (learning stage), participants were instructed to associate three geometric shapes (circle, triangle and square) with three labels (self, friend, and stranger) for approximately 60 seconds. The shape-label associations were counter-balanced across participants. In the second phase (formal experimental phase), participants completed a perceptual matching task. Each trial started with a fixation cross displayed in the center of the screen for 500 ms, followed by a shape-label pairing and fixation cross for 100 ms. the screen then went blank for 1500 ms, or until a response was made. Participants were required to judge whether the presented shape and label matched the learned associations from the learning phase and respond as quickly and accurately as possible by pressing one of two buttons within the allotted timeframe. Prior to the formal experimental phase, participants completed a training session consisting of 24 practice trials. After the training, participants completed six blocks of 60 trials in the matching task, with two matching types (matching/nonmatching) and three shape associations, for a total of 60 trials per association. Short breaks lasting up to 60 seconds were provided after each block.

A diagram of a task

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**Fig. 1.** Procedure of the original SPMT in the Experiment 1 (Sui et al., 2012).

## 2.3 Datasets Acquisition

Initially, two datasets that employed the SPMT were available to us: one from an unpublished project conducted in our laboratory (Hu et al., 2023), and the other provided by our collaborators (Liu et al., 2023). Concurrently, we are conducting a meta-analysis on SPE using the SPMT (pre-registration available at <https://osf.io/euqmf>). During this process, we identified an additional thirteen papers with datasets potentially suitable for our present study. The selection of these papers was based on specific criteria:

1. The paper must primarily utilize the SPMT as their method.
2. The experimental design should not incorporate any stimuli that could potentially trigger a familiarity effect (e.g., using self-face, self-name).
3. The trial-level data is either openly available or declared to be obtainable upon request, enabling us to estimate at least one reliability index.

Among the thirteen papers included, seven papers made their trial-level data publicly available (Constable et al., 2021; Constable & Knoblich, 2020; Golubickis & Macrae, 2021; Navon & Makovski, 2021; Qian et al., 2020; Schäfer & Frings, 2019; Svensson et al., 2022). For the remaining six papers, we reached out to the authors and requested access to their trial-level data. Out of those six requests, three papers provided us with trial level data (Kolvoort et al., 2020; Woźniak et al., 2018; Xu et al., 2021). However, in one article, the author did not provide the explanation of the shape and label in the original data (Kolvoort et al., 2020). As a result, we are unable to analyze the raw data in this context. Two papers provided us only with descriptive results (Cheng & Tseng, 2019; Martínez-Pérez et al., 2020), which unfortunately could not be used for calculating reliability. Additionally, one paper referred to data being shared on the Open Science Framework (OSF) platform (<https://osf.io/pcv3u/>) (Bukowski et al., 2021), but we found that the repository was empty, making it ineligible for the current analysis.

In total, our analysis comprised raw data from nine papers and two unpublished projects from our laboratory and collaborators. It is important to highlight that the research culture discourages direct replications (Makel et al., 2012). As a result, all the datasets included in our analysis underwent some degree of modification to the original design (e.g., change shapes, modify sequence) as well as including the incorporation of additional independent variables (refer to Table 1 for specification). For our analysis, we focused exclusively on using data that adhered to the original design of SPMT, without incorporating any stimuli that could potentially trigger a familiarity effect. Additionally, we specifically utilized data from control conditions in the studies, excluding any conditions that involved the presence of other independent variables (e.g., mood changes). In the end, we were able to incorporate 17 independent datasets from the above-mentioned papers and projects. Nonetheless, not all studies incorporated retest sessions. If a publicly available datasets did not include retest session with SPMT, we excluded it from calculating the Intraclass Correlation Coefficient and only considered the split-half reliability. The details of the included studies and conditions in the datasets are described in Table 1.

Table 1. Dataset Information

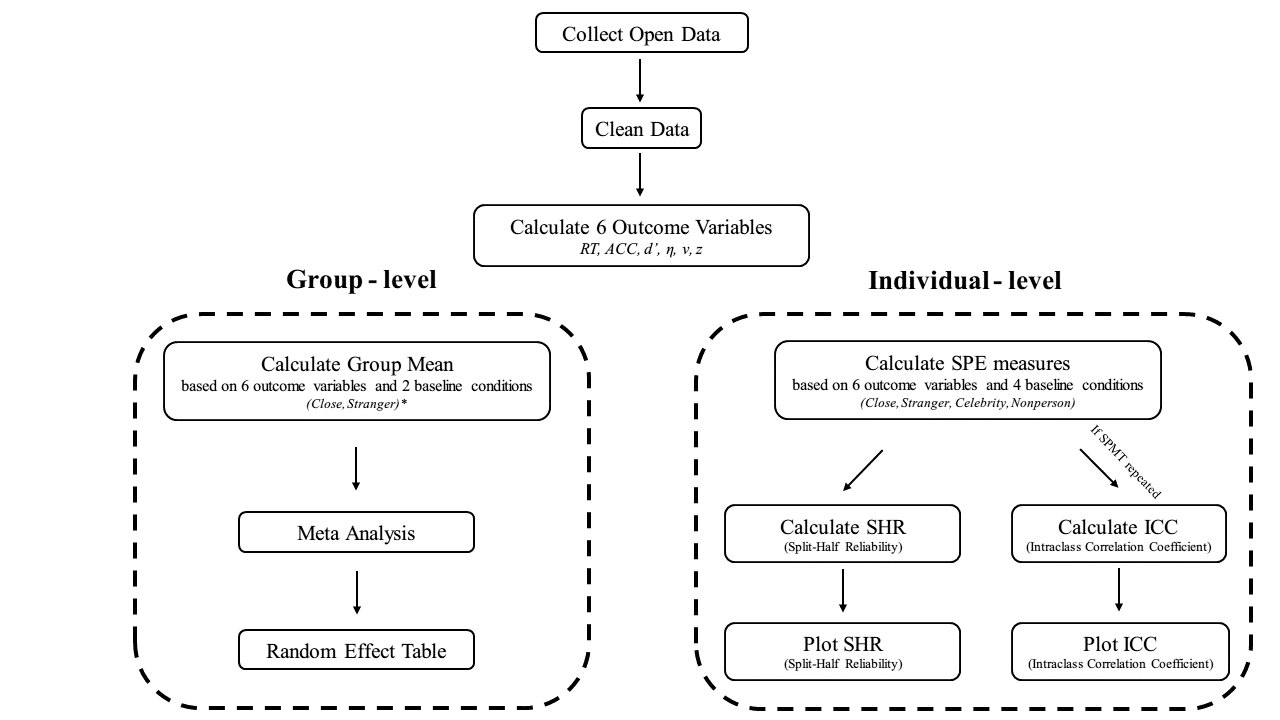
| Author & Publication Year | Study | Independent Variable | | | | Sample  Size | # of Trials per Condition | Self-Prioritization Effect Indices | | | | | | Reliability | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| IV 1 | IV 2 | IV 3 | IV 4 |  |  | RT | ACC | d | Eff | v | z | ICC | SHR |
| Hu et al. (2023) | 1 | Matching | Identity  Self, Friend, Stranger | Emotion  **Control**, Neutral,  Happy, Sad | Session  **1-6** | 33 | 60 | √ | √ | √ | √ | √ | √ | √ | √ |
| Constable and Knoblich (2020) | 1 | Matching | Identity  Self, Friend, Stranger | Switch Identity  Partner, Stranger | Phase  **1**; 2 | 46 | 20 | √ | √ | √ | √ | √ | √ |  | √ |
| Constable et al. (2021) | 2 | Matching | Identity  Self; Stranger |  |  | 56 | 48 | √ | √ | √ | √ | √ | √ |  | √ |
| Qian et al. (2020) | 2 | Matching | Identity Self; Celebrity | Cue  With, **Without** |  | 25 | 25 | √ | √ | √ | √ | √ | √ |  | √ |
| Schäfer and Frings (2019) | 1 | Matching | Identity Self; Mother; Acquaintance/none |  |  | 32 | 18 | √ | √ | √ | √ | √ | √ |  | √ |
| 3 | Matching | Identity Self; Mother; Acquaintance |  |  | 35 | 24 | √ | √ | √ | √ | √ | √ |  | √ |
| Golubickis and Macrae (2021) | 1 | Matching | Identity  Self, Friend, Stranger | Presentation **Mixed;** Blocked |  | 30 | 30 | √ | √ | √ | √ | √ | √ |  | √ |
| Navon and Makovski (2021) | 1 | Matching | Identity  Self, Friend, Stranger |  |  | 13 | 60 | √ | √ | √ | √ | √ | √ |  | √ |
| 3 | Matching | Identity  Self; Father; Stranger |  |  | 28 | 60 | √ | √ | √ | √ | √ | √ |  | √ |
| 4 | Matching | Identity |  |  | 27 | 60 | √ | √ | √ | √ | √ | √ |  | √ |
| Svensson et al. (2022) | 1 | Matching | Identity Self; Friend |  |  | 20 | 50 | √ | √ | √ | √ | √ | √ |  | √ |
| 2 | Matching | Identity Self; Friend | Frequency  self > friend |  | 24 | 100 | √ | √ | √ | √ | √ | √ |  | √ |
| 3 | Matching | Identity Self; Friend | Frequency  self < friend |  | 25 | 100 | √ | √ | √ | √ | √ | √ |  | √ |
| Xu et al. (2021) | 1 | Matching | Identity  Self, Friend, Stranger | Tasks  Modified; **Unmodified** |  | 105 | 60 | √ | √ | √ | √ | √ | √ |  | √ |
| Woźniak et al. (2018) | 1 | Matching | Identity  Self, Friend, Stranger | Facial Gender  Male; Female |  | 18 | 56 | √ | √ | √ | √ | √ | √ |  | √ |
| 2 | Matching | Identity  Self, Friend, Stranger | Facial Gender  Male; Female |  | 18 | 60 | √ | √ | √ | √ | √ | √ |  | √ |
| Liu et al. (2023) | 1 | Matching | Identity  Self; Stranger |  |  | 298 | 16 | √ | √ | √ | √ | √ | √ |  | √ |

*Note*. Study represents different studies from a single article; IV: independent variable. For IV3 and IV4, we only included the baseline conditions that are similar to the original design in Sui et al. (2012), which were highlighted in **BOLD font**. If other variables that could be counterbalanced are indicated by underscores, we will solely utilize these variables as stratification variables during the split-half process

## 2.4 Analysis

Analysis plans for this study were preregistered on OSF (https://osf.io/zv628). All analyses in this paper were performed using the statistical software R (R Core Team, 2023). The drift rate (*v*) and starting point (*z*) of the drift-diffusion model (DDM) was obtained using the “RWiener” package (Wabersich & Vandekerckhove, 2014).

The visual representation of the current study's roadmap can be found in Figure 2 and will be further elucidated in the subsequent sections. After collecting the data from each independent study, we performed data cleaning and then calculated the six outcome variables as well as the twenty-four SPE measures computed using different outcome variables and baseline conditions. Then, we computed the effect sizes (Hedges’ *g*) of these SPE measures. In addition to effect sizes, we calculated the split-half reliability of these SPE measures. If there were test-retest data, we also calculated the test-retest reliability using the intraclass correlation coefficient (ICC2, see Estimating the Reliability Section for details).



**Fig. 2** Roadmap of the Current Study.

*Note:* \*One paper on Celebrity and one on Nonpersons, hence no suitable for a meta-analysis

## 2.4.1 Data Pre-processing

For all the seventeen datasets (see Table 1), we applied the following exclusion criteria for excluding data:

1. Participant exclusion criteria
2. Participants who had wrong trial numbers due to procedure errors is excluded from the analysis,
3. participants with an overall accuracy < 0.5 is excluded from the analysis,
4. participants with any of the conditions with zero accuracy is excluded from the analysis.
5. Trial level data exclusion criteria
6. Trials where the keypress occurs outside the two required keys and non-responsive trials are excluded from the analysis,
7. the practice trials are excluded,
8. the experimental design involved independent variables more than self-referential and matching, e.g., included valence of emotion as a third independent variable.

## 2.4.2 Calculating the Outcome Variables and SPE Measures

For each study, we calculated six outcome variables for each experimental condition: Mean Reaction Time (RT), Accuracy (ACC), Sensitivity Score (*d′*), Efficiency (*η*), Drift Rate (*v*), and Starting Point (z). Reaction Time and Accuracy are obtained directly from the datasets, while Sensitivity Score and Efficiency are calculated based on Reaction Time and Accuracy. SPE Measures were computed using different outcome variables under four baseline conditions (see Table 2).



## Estimating the Robustness of SPE

**Calculation of Effect Sizes.**

In this study, the robustness of experimental effects (group-level effect) of SPE in SPMT is calculated using meta-analytical assessments. In our analysis of effect sizes, we employed a random effects model as the primary approach, given the anticipated heterogeneity among participant sample (Page et al., 2021). The effect size index used for all outcome measures is Hedges’ *g*, a correction of Cohen's *d* that accounts for bias in small sample sizes (Hedges & Olkin, 2014), which represents the magnitude of the difference between the self and baseline condition. Descriptive statistics, including sample size, mean, and standard deviation, are employed to calculate Hedges’ *g* from the datasets.

When calculating Hedges' *g* using Reaction Time and Efficiency, a negative value indicates a perceptual bias towards associating stimuli with the self rather than with baseline associations. Conversely, for the remaining outcome variables, a positive value indicates this bias. For the estimation and interpretation of effect sizes, the absolute value of effect size around 0.2 is interpreted as small effect size, around 0.5 as medium effect size, and around 0.8 as large effect size (Fritz et al., 2012; Hedges & Olkin, 1985).

## Estimating the Reliability of SPE

**Split-half Reliability.** We assessed the split-half reliability by first splitting the trial-level data into two halves and calculating the Pearson correlation coefficients. To ensure methodological rigor, we used four data splitting approaches for splitting the trial-level data: first-second, odd-even, permutated, and Monte Carlo (Kahveci et al., 2022; Pronk et al., 2022). The first-second approach splits trials into the first half and the second half. The odd-even approach splits the trials into sequences based on their odd or even numbers. The permutation approach shuffled the trial order and randomly assigned trials to two halves. The Monte Carlo approach is similar to the permutation approach, but iterates the process multiple times, usually thousands of times, to calculate the average and 95% confidence intervals of the split-half reliability.

In our analyses, we first stratified data by conditions and then employed the above four splitting approaches (Pronk et al., 2022). For example, when using Monte Carlo approach, we randomly split the stratified data into two halves for 5000 times, which resulted in 5000 pairs of two halves of the data. Next, we calculated 5000 Pearson correlation coefficients for these 5000 pairs. After that, we calculated the mean and 95% confidence intervals of the 5000 correlations coefficients. The first-second split, odd-even split, and permutated split are similar to the Monte Carlo approach. However, each of these approaches only results in a single reliability coefficient. Finally, after computing the split-half reliability coefficients for each dataset, substantial variations were observed across the datasets. To derive a more accurate estimation of the average split-half reliability for each SPE measures, we synthesized these reliability coefficients via a meta-analytical approach. We weighed the reliability coefficients based on the trial numbers of each study because the number of trials significantly influences the reliability of cognitive experiments (Kucina et al.2023) (see also Supplementary Fig. 4 for our exploratory analysis). The weighted-average reliabilities was calculated use the “aggregate.escalc” function in the “metafor” Package (Viechtbauer, 2010). We report the synthesized split-half reliability and its 95% confidence interval in the results.

Although there is no strict criterion for defining the level of split-half reliability for psychological and educational measures, a widely accepted guideline for split-half reliability coefficient is that a value of 0.70 is “acceptable”, and a value greater than 0.8 means excellent reliability (Cicchetti & Sparrow, 1981; Kupper & Hafner, 1989).

**Test-Retest Reliability (ICC).** The Intraclass Correlation Coefficient (ICC) serves as a widely recognized measure for evaluating test-retest reliability (Fisher, 1992). Differing from the Pearson correlation coefficient, which primarily quantifies the linear association between two continuous variables, the ICC extends its prowess to scenarios involving multiple measurements taken on the same subjects, while also considers both the correlation and agreement between multiple measurements, making it a more comprehensive measure of test-retest reliability (Koo & Li, 2016).

Since our primary aim is to evaluate the appropriateness of the SPMT in assessing individual differences and repeated administration, to achieve this objective, we assessed the test-retest reliability of the six outcome variables for our dataset that involved test-retest sessions using the function “ICC” in the “psych” package (Revelle, 2017). We focused on using the Two-way random effect model (ICC2) within the ICC family (Chen et al., 2018; Xu et al., 2023). ICC2 gives an estimate of the proportion of total variance in measurements that is attributed to between-subjects variability (individual differences) and within-subjects variability (variability due to repeated measurements) (Xu et al., 2023). For the calculation of ICC2 estimates, the formula is:

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where MSBS is the mean square between subjects, MSE is the mean square error, MSBM is the mean square between measurements, *k* is the number of measurements, *n* is number of participants.

The traditional benchmarks for interpreting ICC values are as follows: ICC less than 0.50 suggests poor reliability; ICC between 0.50 and 0.75 suggests moderate reliability; ICC between 0.75 and 0.9 suggests good reliability; ICC above 0.9 suggests excellent reliability (Cicchetti & Sparrow, 1981; Kupper & Hafner, 1989).

# **3 Deviation from Preregistration**

We adhere to our pre-registration plan as much as possible, however, there are a few differences between the current report and pre-registration document. First, in our initial preregistration plan, we did not anticipate conducting an analysis on the group-level effect of SPE due to the perceived robustness of the effect across a diverse range of research. However, as our study progressed, we recognized the value in providing a more comprehensive assessment. Thus, we include a estimation of pooled effect sizes across included study to represent the group-level effect. Second, we used a different algorithm for estimating parameters of the drift-diffusion model. In the registration, we planned to estimate the drift rate (*v*) and starting point (*z*) of the drift-diffusion model using the “fit\_ezddm” function from the “hausekeep” package (Lin et al., 2020). This function served as a wrapper for the EZ-DDM function (Wagenmakers et al., 2007). However, we found that this algorithm is flawed when estimating parameter *z* during in parameters recovery (details provided in the Supplementary Materials). After comparing the 5 algorithms, we found that the "RWiener" package (Wabersich & Vandekerckhove, 2014) achieved a favorable balance between accuracy, confidence interval width, and computational efficiency, making it the most suitable choice for our analysis. Nevertheless, for transparency, we have included the results from ezDDM in the supplementary materials (see Supplementary, Fig. 2-4). Third, we did not explicitly state in the preregistration report that we would perform a weighted average of the Monte Carlo split-half reliabilities for all obtained studies. However, considering that the number of trials has a significant impact on reliability (Kucina et al., 2023), during the formal analysis, we assigned different weights to each study based on the number of trials and performed a weighted average of the split-half reliabilities. Forth, in our original preregistration, we outlined our intention to include both ICC2 and ICC2k in our data analysis. However, as our understanding of Intraclass Correlation Coefficients (ICC) improved, we realized that ICC2 is the appropriate index for our research purpose. More specifically, ICC2k was mentioned in the preregistration as an index of robustness of group-level effect, but it turned out to be another index of reliaiblity for individual differences. We corrected this mis-interpretation of ICC2k in the final report. Fifth, we conducted exploratory analysis based on the data we collected, exploring the relationship between the number of trials and the Monte Carlo split-half reliability (see Supplementary Fig. 4). Finally, the writing of the current manuscript was improved based on the preregistration. For example, in our preregistration, we include different baseline conditions when calculating SPE in the method section but did not mention this in our introduction and abstract. In this final report, we improved the writing and adjusted the introduction and abstract accordingly.

# **4** **Results**

In seventeen independent datasets, 14 of them contain data for the Self vs Close other contrast, 13 of them contain data for Self vs Stranger, 1 of them have the data for Self vs Celebrities, 1 of them has the data for Self vs none condition. We reported the results for all these baseline conditions.

## 4.1 Group Level Effect of SPE

We conducted a meta-analytical assessment to estimate the group-level effect of SPE in SPMT. Because only one of the papers contains data for the "Self vs Celebrities" comparison, and one paper has data for the "Self vs none" condition, we exclude the Celebrities and none conditions from the analysis of overall effect sizes.

The results, including Hedges’ *g* values and their 95% confidence intervals, along with the outcomes of the random effect model applied to SPE measures, are presented in Table 1. With the exception of the parameter *z*, all other parameters exhibit moderate to large effect sizes. These findings indicate a robust and substantial group-level effect of SPE in SPMT. There were strong evidence of homogeneity among studies. The value, all being greater than 75%, indicates high heterogeneity among studies, justifying the selection of the random effect model (Borenstein et al., 2021).

Table 3. Meta-Analytical Results of SPE Measures in SPMT

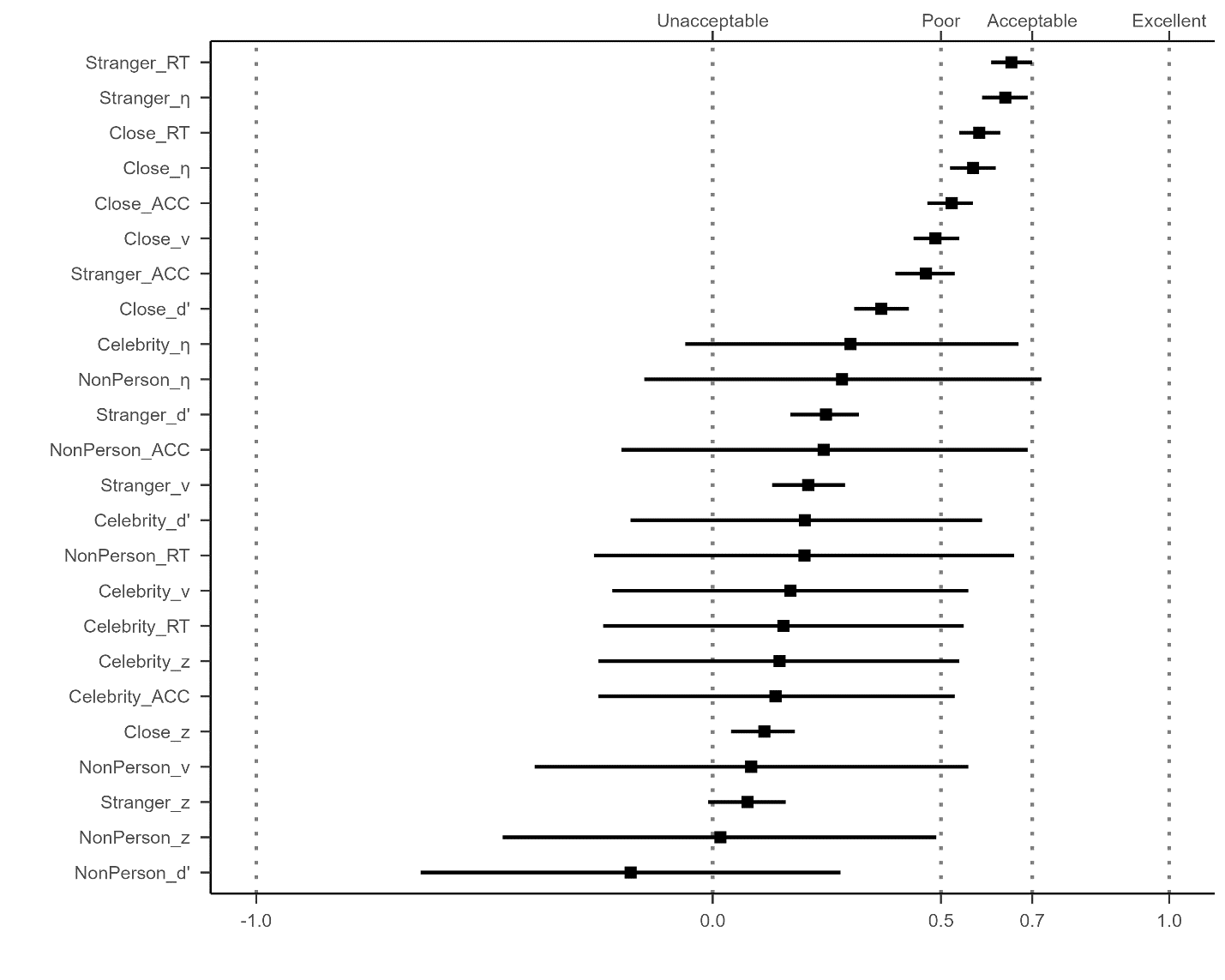
|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Baseline** | **Outcome Variables** | ***g*** | **SE** | **LLCI** | **ULCI** | **No. of**  **Studies** | **Q** | ***p*** | ***I2*** |
| Close |  |  |  |  |  |  |  |  |  |
|  | RT | -.47 | .09 | -.63 | -.30 | 14 | 68.67 | <.001 | 84.94% |
|  | ACC | .73 | .16 | .42 | 1.03 | 14 | 144.57 | <.001 | 92.87% |
|  | *d* | .44 | .08 | .28 | .59 | 14 | 81.96 | <.001 | 83.02% |
|  | *η* | -.88 | .19 | -1.26 | -.50 | 14 | 128.47 | <.001 | 94.67% |
|  | *v* | .54 | .11 | .32 | .76 | 14 | 142.79 | <.001 | 91.16% |
|  | *z* | -.15 | .09 | -.33 | .03 | 14 | 122.30 | .11 | 88.95% |
| Stranger |  |  |  |  |  |  |  |  |  |
|  | RT | -.59 | .10 | -.78 | -.40 | 13 | 55.30 | <.001 | 83.20% |
|  | ACC | .78 | .15 | .48 | 1.08 | 13 | 77.78 | <.001 | 88.60% |
|  | *d* | .35 | .07 | .21 | .50 | 13 | 47.81 | <.001 | 75.38% |
|  | *η* | -.92 | .19 | -1.29 | -.56 | 13 | 98.79 | <.001 | 93.30% |
|  | *v* | .44 | .08 | .28 | .59 | 13 | 50.98 | <.001 | 79.33% |
|  | *z* | .08 | .08 | -.09 | .24 | 13 | 70.48 | .37 | 84.44% |

## 4.2 Split-Half Reliability

As described in method part, we applied four different approaches to split the data when calculating split-half reliability, namely the first-second, odd-even, permuted, and Monte Carlo methods. We presented the results from Monte Carlo split-half method in the main text due to its robustness (Pronk et al. (2022). The results of the other three split-half methods can be found in the supplementary materials (see Supplementary Fig. 2), except the odd-even, the other two also have highly similar result pattern with the Monte Carlo methods.

The split-half reliabilities using of Monte-Carlo method for different SPE measures is presented in figure 3. Among the measured outcome variables, the four highest ranking split-half reliabilities are as follows: Reaction Time (RT) with the "Stranger" contrast (*r* = .65, SE = .02, *p* <.001, 95% CI [.61, .70]); Efficiency (*η*) with the "Stranger" contrast (*r* = .64, SE = .03, *p* <.001, 95% CI [.59, .69]); RT with the "Close other" contrast (*r* = .58, SE = .02, *p* <.001, 95% CI [.54, .63]); *η* with the "Self vs Close" contrast (*r* = .57, SE = .02, *p* <.001, 95% CI [.52, . 62]). These SPE measures achieved a split-half reliability around 0.6 or higher, which is considered an acceptable level of reliability.

For the remaining 4 outcome variables, the reliability is around 0.5 or lower, indicating poor test-retest reliability. These include Accuracy (ACC), Sensitivity Score (*d’*), Drift Rate (*v*), and Starting Point (*z*). It is notice that almost all the split-half reliability of *z* using different contrasts are around 0, which suggests a complete lack of reliability.



**Fig. 3.** The weighted average of split-half reliabilities (Monte-Carlo) for different SPE measures.

*Note:* The vertical axis represents 24 different SPE measures, combining six outcomes variables (RT, ACC, *d’*, *η*, *v*, *z*) and four baseline conditions (close other, stranger, celebrity, and non-person). The weighted average split-half reliability and 95% confidence intervals are shown by points and lines.

## 4.3 Intraclass Correlation Coefficient (ICC)

It is important to note that we could only calculate ICC for the study in our labortory (Hu et al., 2023) since all other datasets did not include re-test sessions. For this dataset, we only have 2 contrasts, the “Close other” and “Stranger”. To test the robustness of the results, we also explored one additional datasets that included re-test session but devivated quite strongly from the original SPMT (see Supplementary Fig. 4).

The ICC2, which measure the reliability for individual differences, aligns with the findings observed in split-half reliability analysis. Specifically, only Reaction Time (RT) and Efficiency demonstrate relatively better reliability, falling within the range of moderate. Specifically, under the "Self vs Close" contrast, the ICC2 for RT is 0.53 (95% CI = [.39, .69]), and for Efficiency, it is 0.52 (95% CI = [.38, .68]). Meanwhile, for the "Self vs Stranger" contrast, the ICC2 for RT is 0.58 (95% CI = [.45, .73]), and for Efficiency, it is 0.35 (95% CI = [.21, .52]). Conversely, all other outcome variables exhibit reliability that is deemed unacceptable or poor.

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**Fig. 4** Intraclass Correlation Coefficient for SPE Measures. ***NOTE:***The vertical axis represents 12 different SPE measures, combining 6 outcomes variables (RT, ACC, d’, η, v, z) and 2 contrasts (close other, stranger). The ICC values and their corresponding 95% confidence intervals are illustrated using points and lines. The dashed line indicates that the confidence interval for that point estimate extends beyond the range of our coordinate axes (0, 1).

# **5 Discussion**

In this pre-registered study, our objective is to investigate the reliability of the different SPE measures in the SPMT. Our analysis reveals that, except parameters *z*, all the other parameters exhibit robust SPE. When assessing reliability of SPE, Reaction Time and Efficiency demonstrated better results in reliability assessment, with split-half reliability around acceptable level, ICC2 around moderate level. In contrast, the remaining SPE measures exhibited subpar performance, with their weighted average split-half reliability ranging from unacceptable to poor and their ICC2 value falling into the poor level. Hence, our analyses suggest that among all the measures within the SPMT, Reaction Time and Efficiency stand out as the most reliable measure of SPE, among all outcome varaibales available in the SPMT. Our results also suggest that the current implementation of SPMT is not well-suited for assessing individual differences. Together, our results revealed a "reliability paradox" of SPE as measured by SPMT. These findings may provide new insight to the study of SPE.

First, the reaction times data and efficiency appear to be the best among all different ways to measure SPE. For the robustness of the SPE, our results revealed that efficiency produced biggest effect size, followed by accuracy and reaction times. For the reliability, reaction times and efficiency are also among the highest. These results suggested the reaction times and efficiency might be the option if researchers are interested in obtaining group-level SPE.

Second, the relatively low reliability of all SPE measures call for future work to make improvement. The reason for low reliability of cognitive tasks has been discussed in several papers (e.g., XXX). As a traditional cogntive task, SPMT share many of these reasons. For example, individual’s performance on SPMT is susceptible to factors such as external conditions and contextual differences, which contribute to greater within-participant variability, lower spli-half reliability and lower test-retest reliability (Clark et al., 2022; Mollon et al., 2017). As the task was invented to get robust SPE instead of measuring individual differences, which means that the design was not optimized for reliability. However, future studies need to address this issue by re-design the SPMT and strike a balance between reliability and robustness, as suggested by (Kucina et al. 2023). for example, increase trials number might help to improve the reliability (see supplementary results for the exploratory analysis of the relationship between trial number and reliability)

~~When assessing the split-half reliability of the SPE measures, it became evident that while Reaction Time and Efficiency performed better compared to other indices, they still did not reach the commonly accepted threshold for excellent split-half reliability (Cicchetti & Sparrow, 1981; Kupper & Hafner, 1989). Several plausible reasons can be identified. Firstly, the insufficient number of trials per condition may contribute to the low split-half reliability. As shown in Supplementary Fig. 4, we calculated the correlation coefficient between the trial numbers and the Monte Carlo split-half reliabilities and found a strong positive correlation between trial number and reliability coefficients. A recent study by Kucina et al. (2023) also emphasized the importance of trial numbers for cognitive tasks in determining reliability. The findings revealed that increasing the number of trials and considering greater conflict effects or individual differences can enhance reliability compared to the original paradigm. Specifically, the study identified that satisfactory reliability required 72 or more trials for RT-stranger-condition, while all the other outcome variables necessitated 100 trials or even more. Therefore, incorporating a larger number of trials in future implementations of the SPMT paradigm may enhance the split-half reliability by improving measurement internal consistency.~~

~~Secondly, it is important to acknowledge the potential influence of serial dependence effects on split-half reliability. In our analysis, we used four distinct data splitting approaches: first-second, odd-even, permutated, and Monte Carlo to evaluate the weighted average split-half reliability of the SPE measures. Interestingly, the results from the odd-even split-half method differed notably from the other three methods, while the permutated, first-second, and Monte Carlo methods showed similar result patterns (see Supplementary figure 2). This discrepancy in the results may be attributed to the presence of serial dependency within the data. Serial dependence refers to the phenomenon in which the outcome of one trial is influenced by preceding trials, resulting in a systematic relationship between consecutive trials (Pascucci et al., 2023). The odd-even method, being sensitive to temporal dependencies, could have been affected by the inherent sequential nature of the responses in the SPMT. Serial dependence effects have been observed in other cognitive tasks, as documented in recent studies (Braun et al., 2018; Zhang & Alais, 2020). Notably, studies in the field of perceptual decision making have demonstrated strong serial dependence effects in perception, even when the visual stimuli were reliable and varied randomly over time (Fischer & Whitney, 2014; John-Saaltink et al., 2016). In particular, if the split-half design unintentionally separates temporally adjacent trials in the SPMT, the presence of serial dependence may introduce performance differences between the halves, leading to a reduction in the reliability estimate. Thus, to accurately control for the impact of serial dependence in experiments, further research should employ appropriate statistical methods that account for the temporal dependencies between trials. Time series analysis techniques (Huitema, 1986) or modeling approaches that capture the serial correlation (Mei et al., 2023) can be utilized to obtain more accurate results.~~

Another results worth noting is

the low split-half reliability and teste-rest reliability of the parameters (*v* and *z*) obtained from the drift diffusion model. In our analysis, we used common and easy-to-use methods to estimate parameter values for each condition of each participant and then calculated the reliability. The reliablity of the drift rate (*v*) and the starting point (z) were at an unsatisfactorily low level. These results indicate that the standard DDM might not adequately capture the underlying cognitive processes in the SPMT , and hence may not be applied to data from SPMT without adhering to a comprehensive cognitive modeling workflow (e.g., Wilson & Collins, 2019). Future research need to examine DDM more carefully and find or develop a model that can capture the cognitive processed of SPMT. Theoretically, this could enhance the reliability of these parameters.

~~Taken the group-level result and individual-level analysis together, our findings align with previously proposed “reliability paradox” in cognitive tasks (Hedge, Powell, & Sumner, 2018; Logie et al., 1996). Like other traditional cognitive tasks such as Flanker, Simon, or Stroop tasks (Clark et al., 2022; Mollon et al., 2017), the SPMT is susceptible to factors such as external conditions and contextual differences, which contribute to greater within-participant variability, lower spli-half reliability and lower test-retest reliability (Clark et al., 2022; Mollon et al., 2017). However, when averaging performance across individuals, the task still demonstrates good consistency, leading to saliant experiemntal effect (Liljequist et al., 2019). Thus, researchers should consider these factors when investigating individual differences using the SPMT. The issue of low reliability at the individual level becomes especially problematic in correlational designs, including those that integrate experimental paradigms with questionnaires and utilize structural equation modeling. These approaches rely largely on natural variability in the measured constructs between different individuals. When there is limited natural variation in the measured variables among individuals, it can weaken the strength of the observed correlations between variables.~~

## Implications and Further Directions

Our study yields practical implications for researchers aiming to use SPMT or improve it. First, our results indicate that Reaction Time and Efficiency emerge as the most reliable measure of SPE, among all measures available in the SPMT. This is particularly true when quantifying the SPE as the contrast between self and stranger condition. The remaining outcome variables demonstrated low levels of internal reliability, and our initial analysis into the factors influencing this individual level reliability deficiency indicates a probable connection to inadequate trial numbers and the emergence of a serial dependence effect.

Second, ~~for researchers interested repeated administration of SPE, it's crucial to be aware that there is a significant degree of variability in the scores acquired from multiple administrations. Consequently, when this task is administered multiple times to the same individuals, it fails to generate consistent results. For researchers who interested in using SPMT as a measure individual difference in SPE, the current version of SPMT demonstrates limitations in capturing trait-like characteristics.~~ Consequently, significant modifications are imperative.

Third, future research could concentrate on modifying the paradigm and conducting tests to assess potential improvements (see Zorowitz and Niv (2023)). For example, if researchers want to use SPMT in assessing individual difference, there is a need for a more nuanced task setting that can consistently capture performance nuances and reveal individual differences more sensitively. Recent study on gamification of cognitive tasks have shown that incorporating gamification elements can effectively improve data quality and assessment efficacy (Friehs et al., 2020). Moreover, Despite the psychometric shortcomings in assessing individual difference, Enkavi et al. (2019) propose that the results of cognitive tasks' outcome variables can be combined using data-driven methods. These methods aim to derive more consistent latent variables, which could be better suited for trait-like treatment. Hence, introducing modifications to the SPMT by integrating dynamic elements, such as gamification components, or using data-driven approach to undriveable latent variables of SPMT holds the potential to amplify its efficacy in capturing distinctive individual variations. These further explorations will have important implications for future task design and data collection protocols.

## Limitations

Several limitations warrant acknowledgment. Firstly, although we made efforts to enhance sample diversity by including open data whenever possible, it is important to note that the majority of our samples still consisted of individuals from what is commonly referred to as "WEIRD" populations (Rad et al., 2018; Yue et al., 2023). As a result, our findings may not be fully representative of the broader population, and it is necessary to include a more diverse sample to ensure greater generalizability of the paradigm. Additionally, when assessing the intraclass correlation coefficients (ICCs), only one dataset had longitudinal data available, which could potentially limit the representativeness of the results. This issue is mitigated by the fact that additional analysis of two datasets that with different design showed similar results as we reported in the main text. Furthermore, the majority of the studies included in our analysis focused on adults from healthy populations. Therefore, further investigation is needed to include more datasets with a more diverse population in order to determine the reliability of the SPMT in different settings. Finally, we did not use hierarchical models, which may reveal different results. We are doing so to reveal the reliability of the conventional ways of measuring SPE. Future studies may consider introducing new statistical methods to improve the reliability of SPMT.

# **6 Conclusion**

This study provides an empictal assessment of the reliability of the self-perceptual matching task (SPMT). We found a robust self-prioritization effect for reaction times, efficiency, and accuracy, mean while, the reliability of the most reliability SPE measure, Reaction Time and Efficiency, are not satifactory. The results of the current study may serve as a bench marker for the improvement of future studies.**Acknowledgements**

The authors declare that this research received no external funding.

# **Author contributions**

HCP contributed to the conception and supervision of the study. HCP contributed to data collection. ZL, ZYR and HMZ write the simulation code for pre-registration. HMZ collected the datasets and performed the data pre-processing, analysis and visualize the results. In addition, ZL, HMZ and HCP contribute to discussing the results and the drafting of the final manuscript. HCP, JS, ZL and HMZ critically revise the manuscript.

# **Data and Material Availability**

The pre-registration plan is available at <https://osf.io/zv628>. The de-identified raw data from our lab is available at <https://doi.org/10.57760/sciencedb.08117>. The simulated data is accessible on GitHub (<https://github.com/Chuan-Peng-Lab/ReliabilitySPE>).

# **Code Availability**

Code used to simulate and analyze the data is made accessible at <https://github.com/Chuan-Peng-Lab/ReliabilitySPE>.

# **Competing interests**

The authors declare no competing interests.

# **Supplementary Information**

## Parameter Recovery Result for Package Comparison

We chose not to utilize the HDDM package (Wiecki et al., 2013) since the computation process is significantly time-consuming, necessitating high computational resources and leading to prolonged overall analysis time. Instead, we performed a package comparison by generating 100 datasets using the HDDM package in Python, in order to identify the most appropriate package for our analysis. These datasets were specifically configured with parameters *a* = 2, *t* = 0.3, *v* = 1, and *z* = 0.7. Subsequently, we utilized three different DDM packages in R, namely RWiener (Viechtbauer, 2010), hausekeep (Lin, 2019), and FastDMinR (Voss & Voss, 2007), to compute parameter estimates for these generated datasets. The evaluation process involves comparing the computed values obtained from the R packages with the set parameters. If the computed values from the R packages are found to be closer to the set values, it signifies that the respective R package provides more accurate parameter estimation for the drift-diffusion model.

Figure 1 presents the results of the package comparison. The estimated drift rate (*v*) obtained from RWiener is 1.01, with a 95% confidence interval of [.98, 1.03], which closely aligns with our pre-defined values. Similarly, the estimated starting point (*z*) is 0.77, with a 95% confidence interval of [.76, .78], also very close to our pre-defined value. On the contrary, the parameters calculated using other packages either showed high inaccuracies, excessively wide confidence intervals, or required extended computation times. As a result, we have opted to utilize RWiener for our calculations. It strikes a favorable balance between accuracy, confidence interval width, and computational efficiency, making it the most suitable choice for our analysis.



**Supplementary Fig. 1 DDM Packages Comparison.**

*Note:* The parameters of interest in the drift-diffusion model (DDM) are represented as follows: "*a*" denotes the threshold parameter, "*t*" represents the non-decision time, "*v*" indicates the drift rate, and "*z*" corresponds to the starting point. The y-axis of the graph displays the estimation of these DDM parameters using three different R packages: "RWiener," "hausekeep," and "FastDMinR." In total, there are five methods for estimating DDM parameters, with three methods originating from the "FastDMinR" package. On the x-axis, the values of the estimated parameters are plotted. The dashed line on the graph indicates the true value of the parameter being estimated.

* 1. **Split-half Reliabilities Using Four Splitting approaches.**

In this section, we are presenting the split-half reliabilities results for the SPE measures using four split-half methods: Monte Carlo, first-second, odd-even, and permutated. We also include includes the drift rate (*v*) and starting point (*z*) estimated from the "hausekeep" package in the analysis. However, it is important to highlight that the estimation of parameter "*a*" in "hausekeep" significantly deviates from the HDDM approach, primarily because of the assumption that *z* = *a* / 2 (refer to suppl. Fig. 1). As a result, we have chosen not to include the results obtained from this package in the main text. Nevertheless, we present them here for reference and transparency. Please refer to Figure 2(a-d) for the visual representation of the results.

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**Supplementary Fig. 2a Results of Split-half Reliabilities using Monte Carlo Split-half Methods.**

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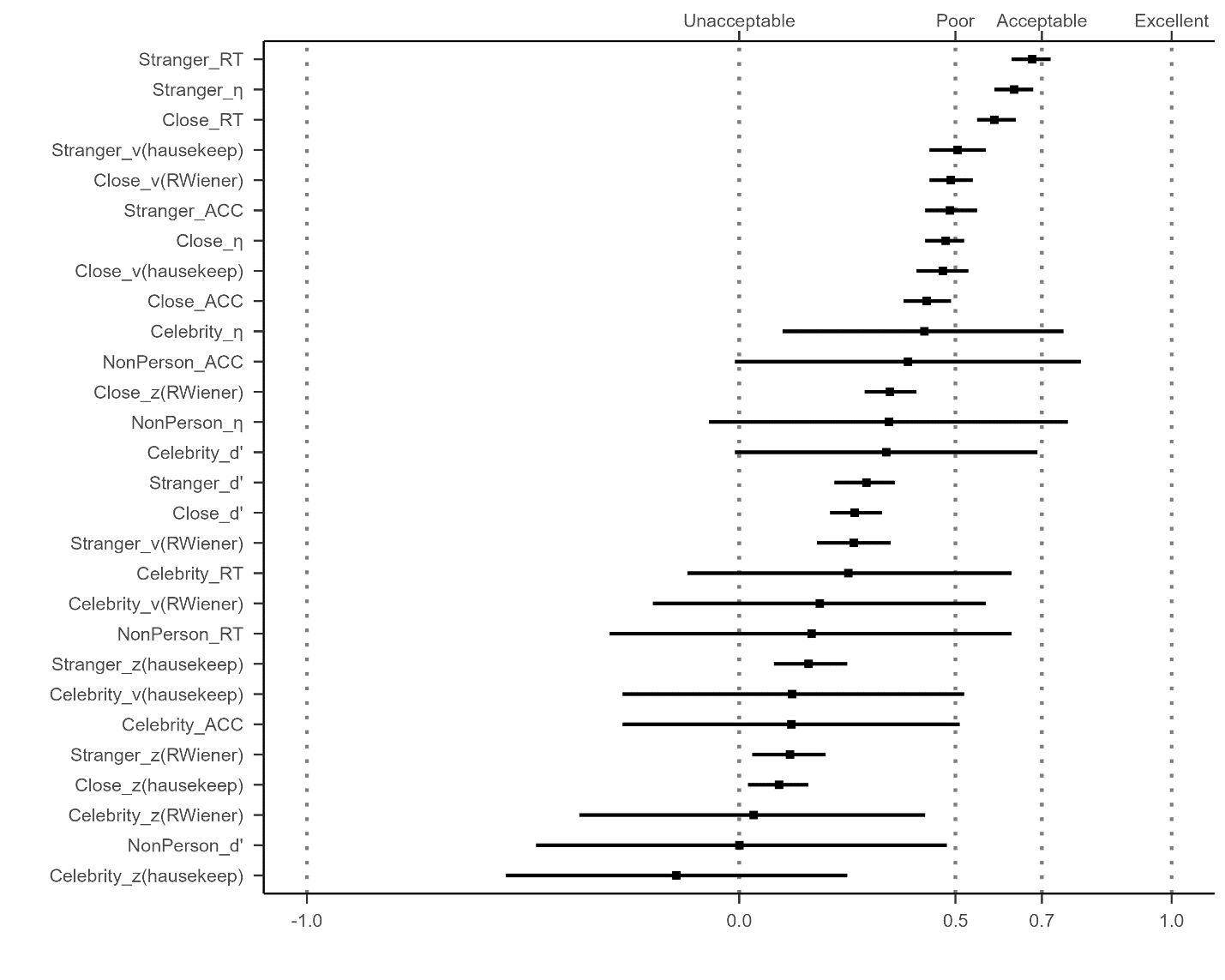
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**Supplementary Fig. 2b Results of Split-half Reliabilities using First-Second Split-half Methods.**

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**Supplementary Fig. 2c** **Results of Split-half Reliabilities using Odd-Even Split-half Methods.**



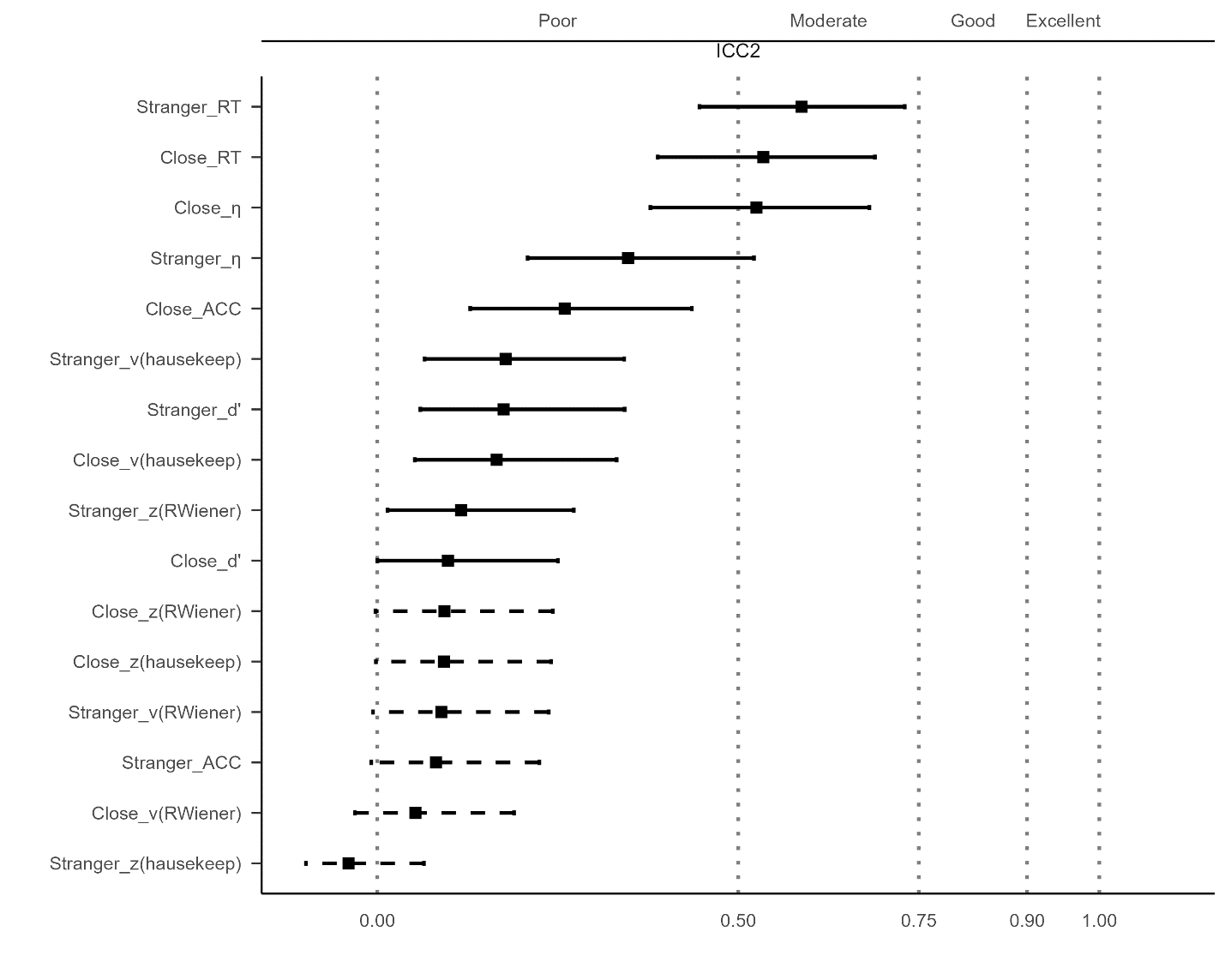
**Supplementary Fig. 2d** **Results of Split-half Reliabilities using Permuted Split-half Methods.**

*Note:* The vertical axis of the graph listed 32 different SPE measures, combining six outcomes variables (RT, ACC, *d’, η, v, z*) and four baseline conditions (close other, stranger, celebrity, and non-person). The *v* and *z* implemented using the "hausekeep" package were also included. The weighted average split-half reliability and 95% confidence intervals are shown by points and lines. The figure is divided into separate facets arranged from left to right, each representing weighted average split-half reliability calculated using three distinct methods: first-second, odd-even, and permuted.

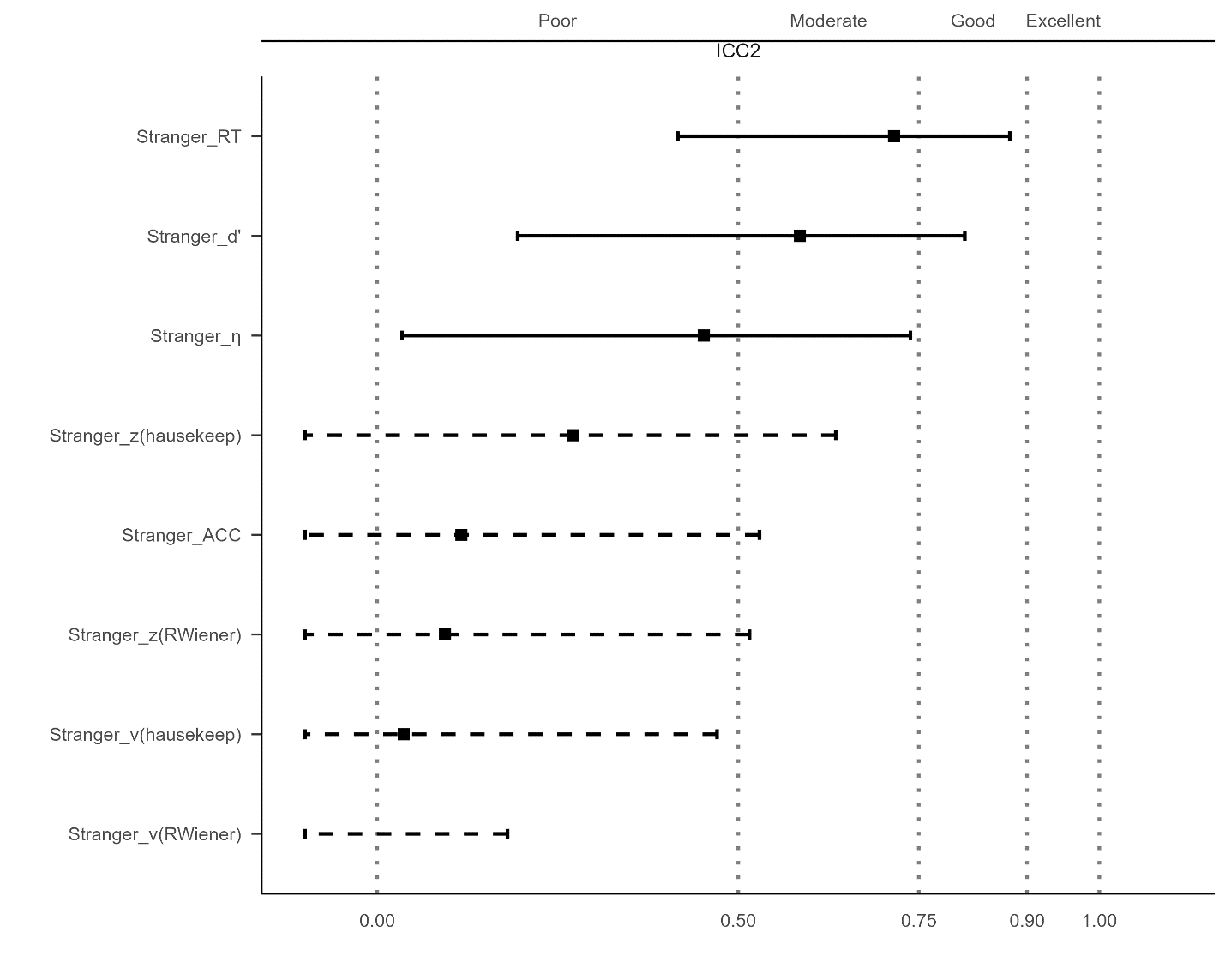
It is evident that the results pattern from the permuted split-half methods and first-second split-half methods closely resemble the Monte Carlo method's outcomes. The top four split-half reliabilities, ranked highest, are as follows: Reaction Time (RT) with the "Stranger" contrast, Efficiency (*η*) with the "Stranger" contrast, RT with the "Close other" contrast, *η* with the "Self vs Close" contrast. However, the results obtained from the odd-even split-half method were notably different from the other three methods. We hypothesize that this discrepancy may be attributed to the presence of serial dependency within the data (see discussion section). Further investigation into the presence and impact of serial dependency in the data would be valuable to better understand the observed variations in the split-half reliabilities among the different methods.

## ICCs for SPE Measures Using Other Dataset

In Figure 3a, we present the results of the Intraclass Correlation Coefficients (ICC2) for the SPE measures, where drift rate (*v*) and starting point (*z*) estimated from the "hausekeep" package were also included. In Figure 3b, we extended our exploration of ICC2 to include the SPE measures from one additional dataset. However, it is important to note that the SPMT used in this dataset deviated quite strongly from the original SPMT paradigm. Due to these significant differences, ICC2 obtained from this dataset may reflect variations introduced by the modified SPMT rather than directly comparable results to the original paradigm.



**Supplementary Fig. 3a ICC2 for SPE Measures Using Hu et al. (2023).**



**Supplementary Fig. 3b ICC2 for SPE Measures Using an Aditional dataset.**

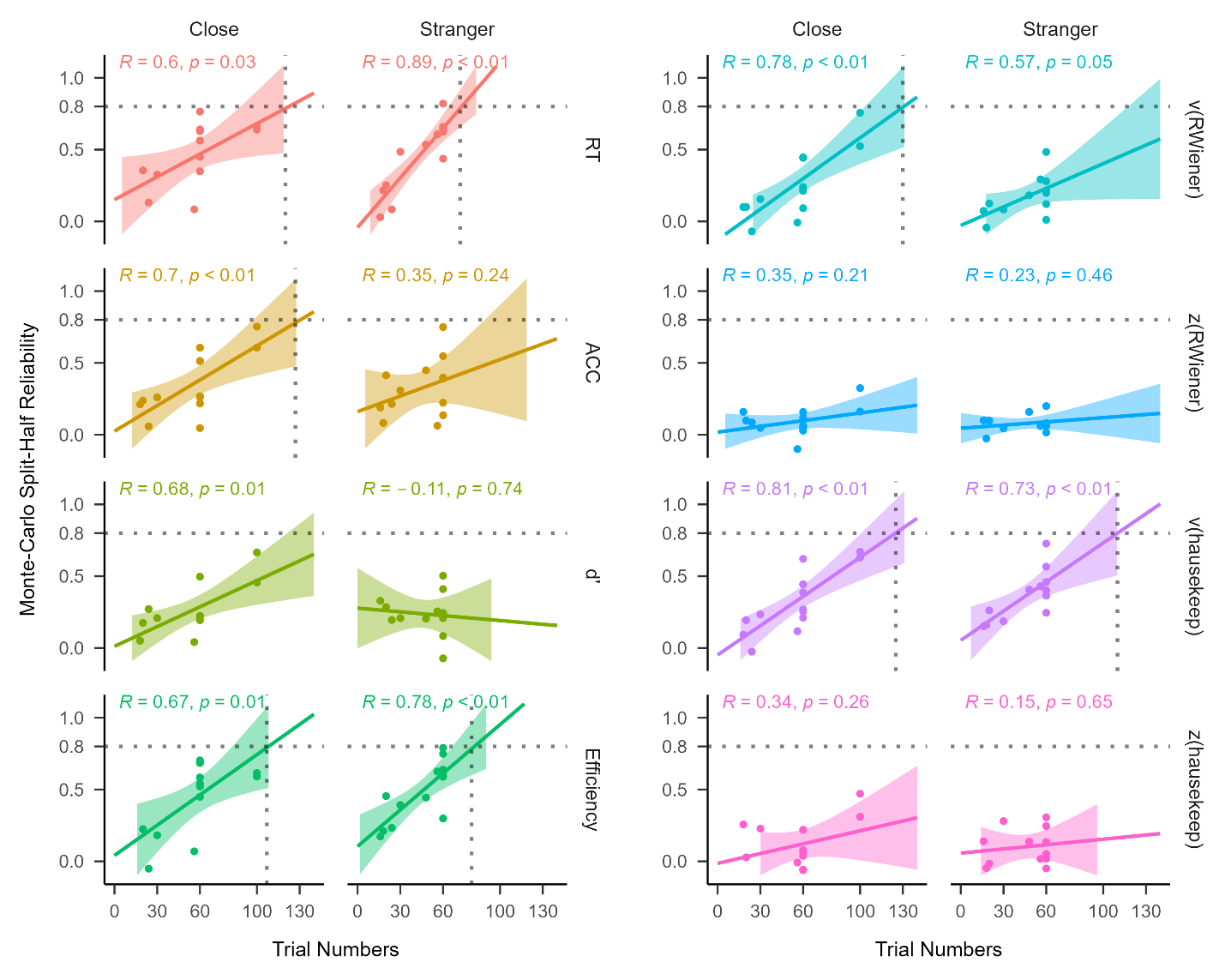
*Note:*The vertical axis of the graph illustrates eight distinct outcome variables, which includes two additional indices from the DDM, implemented using the "hausekeep" package. The line and dots on the graph represent the value of ICC2, along with their corresponding 95% confidence intervals. The dashed line indicates that the confidence interval for that point estimate extends beyond the range of our coordinate axes (0, 1).

## Correlation Between Monte Carlo Split-half Reliability and Trial Numbers

In this section, we present the results of the correlation analysis between Monte Carlo split-half reliability and the number of trials (Fig. 4). Notably, we found significant correlations between Monte Carlo split-half reliability and trial numbers for some outcome variables, such as Reaction Time and Efficiency. However, for outcome variables like *d'* and *v*, the correlation with trial numbers was relatively weak.

From the plot, we can observe that the SPMT paradigm requires approximately 80 trials to achieve a Monte Carlo split-half reliability of 0.8 for the SPE measure of RT under the 'Stranger' condition and around 120 trials under the 'Close' condition. Furthermore, achieving a Monte Carlo split-half reliability of 0.8 for the *v* parameter may require more than 120 trials. On the other hand, attaining high Monte Carlo SHR values for the remaining three outcome variables, particularly for the *z* parameter, remains challenging even with 150 or more trials.

It is important to emphasize that here we only conducted a simple regression analysis of trial numbers and Monte Carlo SHR based on the collected datasets. This analysis was not part of the pre-registered plan, and our primary aim was not to provide a well-validated improvement for the SPMT. However, considering the significant correlation between the number of trials and Monte Carlo split-half reliability, our findings suggest that, for the SPMT paradigm, achieving higher reliability for clinical evaluation would necessitate conducting more trials. As a reasonable approach, it might be beneficial to consider having more than at least 80 trials under each experimental condition.



**Supplementary Fig. 4 Regression analysis between Monte Carlo split-half reliability and trial numbers using different SPE measures.**

*Note:* The vertical axis represents Monte-Carlo split-half reliability, and the horizontal axis represents the number of trials. Each facet represents one SPE measures.

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