RESEARCH ARTICLE

Pre-crastination and procrastination effects occur in a reach-to-grasp task

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Abstract

How do we decide which object to pick up when faced with two alternatives? Imagine one object is near, but needs to be carried a long distance, and the other object is far, but needs to be carried a short distance. You might predict that participants would favour the far object that needs to be carried a short distance. In other words, they would procrastinate and delay picking up an object to minimise physical effort. In actuality, participants prefer to carry the near object a long distance, which is called pre-crastination. Pre-crastination may be preferred to procrastination because picking up the first object hastens completion of the first goal of the task and, subsequently, decreases cognitive load. The goal of the current study was to further investigate the mechanisms of the pre-crastination effect. This was done by converting the primarily walking task used in the first study on pre-crastination to a reach-to-grasp task. This change enabled the measurement of the duration of information processing (i.e., reaction time) when participants decided which object to move. Surprisingly, participants exhibited a range of behaviours: about 40% pre-crastinated, 40% procrastinated, and 20% neither pre-crastinated nor procrastinated. We suggest that scaling the task down from a walking task to a reach-to-grasp task altered the physical effort, cognitive load, and the interaction between these task demands. This enabled some participants to pre-crastinate and others to procrastinate. There was an intriguing relationship between the duration of information processing and the behaviour of participants: participants with the shortest reaction time had the strongest tendency to pre-crastinate, and participants with the longest reaction time had the strongest tendency to procrastinate. These findings fit with the automatic pre-crastination response hypothesis; that the "decision" to pre-crastinate is automatic. This automaticity caused the short durations of information processing for participants who pre-crastinated. Participants who procrastinated had to, first, inhibit the automatic response to pre-crastinate, which caused long durations of information processing.

Keywords Two-alternative forced choice task · Information processing · Reaction time · Trajectory analysis

Introduction

How do we decide which object to pick up when faced with two alternatives? Rosenbaum et al. (2014) investigated how the participants' decision of which object to pick up was affected by the distance which they had to walk to reach the object and the distance it then had to be carried. Imagine that one object is near, but needs to be carried a long distance, and the other object is far, but needs to be carried a short distance. Rosenbaum and colleagues predicted that participants would favour the far object that needs to be carried a short distance. In other words, participants would procrastinate; they would delay picking up an object by walking past the near object to the far one. This decision would minimise physical effort, because the far object only needed to be carried a short distance. Rosenbaum and colleagues were surprised that over 200 hundred participants across multiple experiments preferred to choose the near object and carry it a long distance. They called this behaviour pre-crastination, because it was the opposite of procrastination. Their hypothesis was that participants were minimising the cognitive load of holding the goals for the task. Participants had to remember two goals: pick up an object and put it down at the end. By selecting the near object, they held the first goal for a short duration rather than a long duration, which minimised cognitive load. The purpose of the present study was to extend the pre-crastination effect from a primarily

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walking task to a reach-to-grasp task. This allowed us to investigate the mechanisms of the pre-crastination effect in two ways that are challenging with a walking task. First, we measured the duration of information processing when selecting an object by recording reaction time (RT). Second, we examined exactly how movements unfolded with trajectory analysis.

The experiments by Rosenbaum et al. (2014) involved participants walking down a 16-foot-long alley. As the participants walked down the alley, they passed eight waist-high platforms placed in pairs, with four on the left and four on the right. A bucket was placed on one of the four platforms on the right, and another bucket was placed on one of the platforms on the left. There were 16 different placements of the two buckets that were achieved by combining the four positions on the left with the four positions on the right. There was also a final pair of platforms at the end of the alley. Participants were instructed "to do whatever seemed easier—pick up and carry the left bucket to the far left platform with the left hand, or pick up and carry the right bucket to the far right platform with the right hand" (p 1488). The results in the first three experiments suggested that participants preferred to choose the closer of the two buckets, regardless of which side it was on. In other words, they pre-crastinated; they selected the closer bucket to minimise cognitive load by completing the first goal as soon as possible. This occurred even at the expense of increased physical effort to carry the bucket farther.

Rosenbaum et al. (2014) investigated the pre-crastination effect with more experiments in the same study. They tested whether the approach distances to the buckets or the carry distances after the buckets caused the pre-crastination effect (Experiment 7). The results suggested that the pre-crastination effect was caused by the distance to approach the buckets. This fit with the hypothesis that participants chose the near bucket to complete the first goal and minimise cognitive load. A subsequent experiment by Fournier et al. (2018) with a similar but sequential task suggested that pre-crastination is caused by the preference to begin the goal, rather than to complete it. The last experiment by Rosenbaum et al. (2014) tested how physical effort affected pre-crastination. This was done by manipulating the weight of the buckets: one was empty and the other held seven pounds of pennies. They found the decision of which bucket to choose was largely determined by weight. Rosenbaum and colleagues argued that many factors, including cognitive load and physical effort, can influence which bucket is chosen. When the buckets weigh the same, this decision is dominated by cognitive load. However, this decision is dominated by physical effort when one bucket is heavier than the other. The factors affecting bucket choice were further investigated by Potts et al. (2018). The overall finding

was that there is a strong tendency to pre-crastinate, but that tendency can be eliminated by increasing the physical effort to carry the closer bucket.

The goal of the current study was to further investigate the mechanisms of the pre-crastination effect. There are several theoretical approaches that can explain the pre-crastination effect (e.g., Richter 2015). We were particularly interested in the hypothesis that the closer object is automatically selected. Fournier et al. (2018) argued that perception of the closer object automatically activated the object's affordance to pick it up. By relying on the automatic activation of affordances, the participant decreases cognitive load and frees up cognitive resources for other demands. Selecting the farther object, or procrastinating, would require inhibiting the automatic selection of the closer object. This would, in contrast to pre-crastination, increase cognitive load and consume cognitive resources. Thus, pre-crastination may be preferred over procrastination, because it decreases cognitive load, even though it increases physical effort. We referred to this as the automatic pre-crastination response hypothesis. If this hypothesis is true, then the duration of movement preparation should be shorter to pre-crastinate than to procrastinate, which was tested in the present experiment.

Our approach to investigating the mechanisms of the pre-crastination effect was achieved by altering the typical task. We converted the primarily walking task used by Rosenbaum et al. (2014) to a reach-to-grasp task using blocks. This change enabled the measurement of the duration of information processing when participants decided which block to move. The pre-crastination effect entails selecting the closer of the two blocks. When the two blocks are far apart, it should be obvious which one is closer. We, therefore, predicted that the decision between blocks in this situation would be easy, making information processing short. When the blocks are close, but not at the same distance, we predicted that the decision would be hard and information processing long. Rosenbaum et al. (2014) showed that participants strongly preferred the right bucket when the buckets were at the same distance. This may have been a preference for their dominant hand (the vast majority of participants were right handed). We, therefore, predicted that the decision between blocks at the same distance would be easy, again making information processing short. Our examination of movement trajectories was more exploratory. We were interested whether there were differences in the trajectories that could suggest why one block was preferred over the other. Our hypotheses were based on the assumption that the vast majority of participants would pre-crastinate. We were surprised that about 40% of our participants pre-crastinated, 40% procrastinated, and 20% neither pre-crastinated nor procrastinated. Consequently, analyses were added to determine whether differences in the duration of information
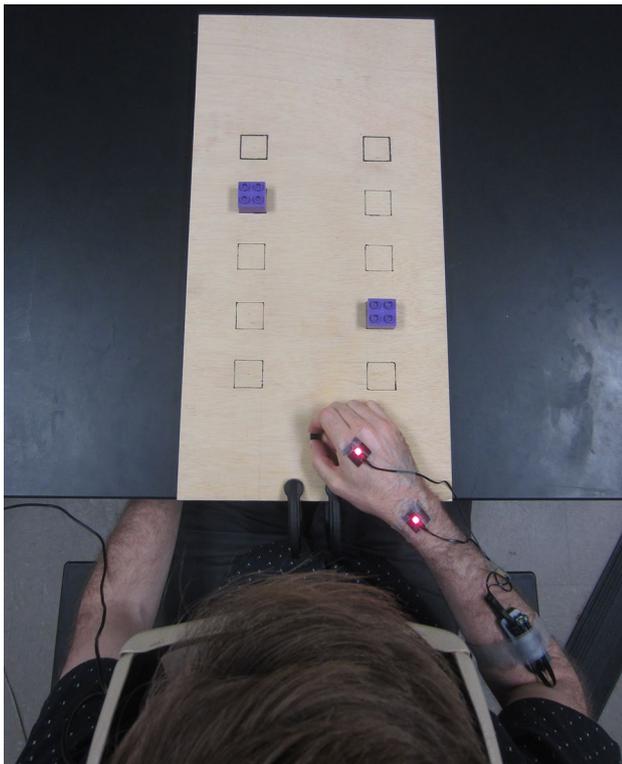
Fig. 1 A participant seated at the apparatus. They are grasping the home position with their dominant hand as they await the "go" signal. The left block is in the fourth row and the right block is in the second row, which is condition (4,2)

processing or trajectories could differentiate pre-crastinators from procrastinators.

Method

Participants

Fifty-two volunteer participants (mean age of 22.5 ± 1.7 years; 33 female and 19 male) were tested from the university community. All participants reported that they had normal or corrected-to-normal vision. A modified version of the Edinburgh (Oldfield 1971) and Waterloo (Brown et al. 2006) handedness questionnaires (see Stone et al. 2013 for the questionnaire) determined that 50 participants were right-handed (scores ≥ 0.5), one was left-handed (scores ≤ -0.5), and one had inconsistent handedness ($-0.5 <$ scores < 0.5). The research ethics board at Texas Tech University approved the study.

Apparatus

The participant was seated at a table, with their midsagittal plane centered with a board clamped to the table (Fig. 1). On the surface of the board was a five-row by two-column grid of target placeholders (each 32×32 mm). The distance between rows was 70 mm, and the two columns were 150 mm apart. The participant was seated close enough to the table that they could reach the fifth row of target placeholders with their trunk stationary. There were two target objects, 2×2 Mega Bloks ($31.5 \times 31.5 \times 23.5$ mm), that fit inside the target placeholders. Thin foam (1.5 mm) was attached to the bottom of the target objects. A 1×1 Lego brick ($7.8 \times 7.8 \times 11.4$ mm) was glued 70 mm in front of the first row of target placeholders and between the two columns.

Two light-emitting diodes were taped to the participant's dominant hand: one on the metacarpophalangeal joint of the index finger, and one on the dorsal tubercle of the radius. A PhaseSpace Improv motion capture system with six detectors recorded the positions of the light-emitting diodes at 270 Hz. The participant wore PLATO visual occlusion spectacles (Translucent Technologies) that controlled their access to visual information during and between trials.

Procedures

Each trial began with the PLATO spectacles closed to occlude visual information. The participant used their somatosensory system and their memory to pincer grasp the home position with their dominant hand (index finger in front of the Lego brick and thumb behind). While the participant moved to the home position, the experimenter placed the first block in one of the first four target placeholders on the left and the second block in one of the first four target placeholders on the right. The fifth target placeholders were reserved as the goal locations for the reach-to-grasp movements. The blocks were moved silently into position to prevent the participant from receiving auditory cues as to their positions. This was ensured by the thin layer of foam added to the bottom of the blocks and by gently placing the blocks. The participant was instructed to "pick whichever block seems easier and move it to the goal location as quickly and accurately as possible". If the participant selected the block on the left, for example, then it should be moved to the goal placeholder also on the left. The "go" signal was the opening of the spectacles. The participant then reached for one of the blocks, grasped it with a pincer grasp, and lifted it to the goal placeholder. They maintained their grasp on the block until the end of the 2.0 s recording interval of the motion capture system.

The spectacles then closed, the participant released the block, and they moved back to the home position to begin the next trial.

Design

Each participant completed 128 trials split into two blocks with a short break in-between. There were eight repetitions of the 16 conditions. The 16 conditions were created by crossing the four potential block locations on the left with the four block locations on the right. The left block, for example, could be in the target placeholder in the first, second, third, or fourth rows, with the first row being closest to the home position. The conditions were abbreviated with the position of the left block follow by the right block: (1,1), (1,2), (1,3), (1,4), (2,1), (2,2), (2,3), (2,4), (3,1), (3,2), (3,3), (3,4), (4,1), (4,2), (4,3), and (4,4). Each of these 16 conditions were presented eight times to every participant. Each condition had an approach score, which was calculated as the position of the left block divided by the position of the left block plus the right block. The smallest approach score was 0.2 for condition (1,4) $[1/(1+4)=0.2]$. Conditions where the blocks were in the same position $[(1,1), (2,2), (3,3),$ and $(4,4)]$ all had an approach score of 0.5. The largest approach score was 0.8 for condition (4,1) $[4/(4+1)=0.8]$. Both blocks of 64 trials were composed of four sets of 16 trials, and each set of 16 trials contained one repetition of each condition in a randomised order. A new randomization was used for each set, block, and participant.

Data analysis

The position data were filtered with a low-pass Butterworth filter (dual-pass, second-order) with a cut-off frequency of 20 Hz. Tangential velocity of the wrist was calculated with a three-point central difference method. Movement initiation was calculated as the first time that tangential velocity exceeded 50 mm/s and stayed above this threshold for 51.9 ms (14 frames). Movement termination was calculated as the first time after peak tangential velocity that velocity was less than 50 mm/s and remained below this threshold for 51.9 ms. Movement initiation and termination for each trial were visually inspected and corrected when necessary. Reaction time was calculated as the interval between the "go" signal (opening of the spectacles) and movement initiation.[1]

The probability of choosing the right block was calculated for each condition and participant. Recall that each participant completed eight repetitions of the 16 conditions.

In condition (1,4), for example, if the participant chose the left block on two trials and the right block on six trials, then their probability of choosing the right block is 0.75 (6/[2+6]). A Pearson correlation coefficient between approach score and probability of choosing the right block in all the conditions was calculated for each participant. More specifically, the approach scores in the 16 conditions were correlated with the probabilities of choosing the right block in the 16 conditions. A positive correlation coefficient suggested the participant preferred the left block when the left block was closer than the right block and they preferred the right block when the right block was closer than the left block. In other words, the participant preferred the closer object; that is, they pre-crastinated. A negative correlation suggested that the participant preferred the farther object; that is, they procrastinated. Participants with a positive correlation with at least a medium-effect size $(r \geq 0.29)$ were classified as pre-crastinators. Participants with a negative correlation with at least a medium-effect size $(r \leq -0.29)$ were classified as procrastinators. Participants with correlation coefficients between these two groups $(-0.029 < r < 0.29)$ were classified as neither pre-crastinators nor procrastinators. We defined pre-crastinators and procrastinators by correlations with at least medium-effect sizes to ensure a fairly clear relationship between approach score and probability.

Reaction time was subjected to two statistical analyses. First, we analysed whether reaction time depended on how far the blocks were apart; for example, the blocks were three rows apart in conditions (1,4) and (4,1). To calculate mean reaction time for each participant, we included different trials for pre- and procrastinators. For pre-crastinators, we included trials where they chose the left block in condition (1,4) and the right block in condition (4,1) (i.e., the closer block). For procrastinators, we included trials where they chose the right block in condition (1,4) and the left block in condition (4,1) (i.e., the farther block). This was replicated in the conditions where the blocks were zero $[(1,1), (2,2), (3,3), (4,4)]$, one $[(1,2), (2,1), (2,3), (3,2), (3,4), (4,3)]$, and two $[(1,3), (2,4), (3,1), (4,2)]$ rows apart. We included pre- and procrastinators for two reasons. First, we predicted that pre- and procrastinators would show the same trend of shorter reaction time when the blocks are farther apart. Second, reaction time is often longer to reach a long distance compared to a short distance (Klapp [1995], [2003]); for example, reaching for a block in the fourth row (long amplitude) compared to a block in the first row (short amplitude). We controlled for this possible confound by including both pre- and procrastinators; the mean block position was 2.5 regardless of whether the blocks were zero, one, two, or three rows apart. This was only possible by including pre- and procrastinators.

The second statistical analysis on reaction time compared pre- and procrastinators. This analysis tested the automatic

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[1] The reaction time results were comparable when the absolute tangential velocity threshold was replaced with a relative tangential velocity threshold of 5% of the initial reach to the selected block.
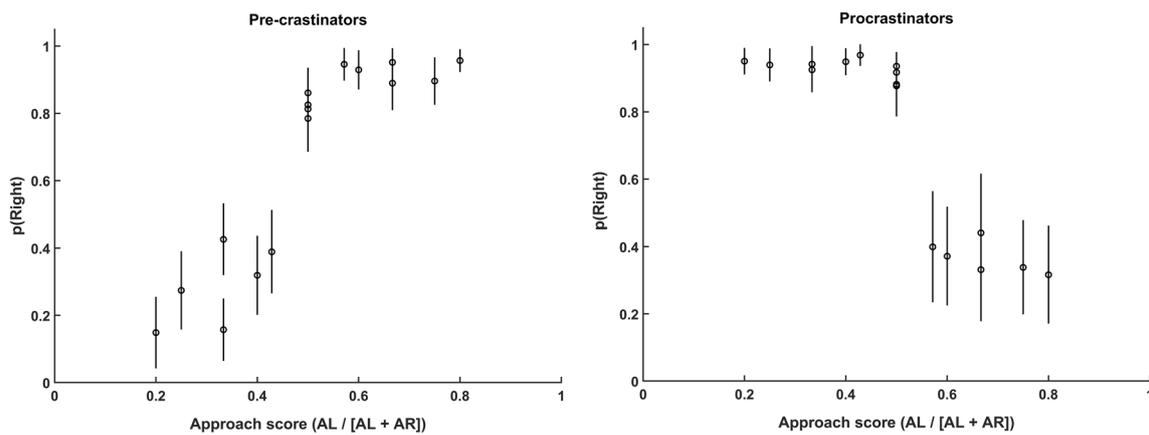
Fig. 2 Mean probabilities of selecting the right block for the range of approach scores of pre-crastinators (left) and procrastinators (right). Approach score was calculated as the position of the left block divided by the position of the left block plus the right block. Error bars are 95% confidence intervals

pre-crastination response hypothesis; more specifically, that the duration of movement preparation is shorter for participants that pre-crastination than those that procrastinate. The analysis was carefully designed to ensure a fair comparison between groups. We could not simply compare trials in the same condition. In the (1,4) condition, for example, pre-crastinators usually chose the left block and procrastinators usually chose the right block. Reaction time could be shorter for pre-crastinators than procrastinators, because the movement amplitude was shorter. Conversely, reaction time could be shorter for procrastinators than pre-crastinators, because they chose the block on their dominant, right side (96% of participants were right handed). We controlled for these possible confounds by comparing reaction time to the same block positions for pre- and procrastinators. This was done using different conditions for the two groups. One of the comparisons was reaction time of movements to blocks in the second row on the left side. We included reaction time when the participant chose the left block in the second row in the (2,3) condition for pre-crastinators and the (2,1) condition for procrastinators. The limitation of this analysis was that blocks in only the second and third rows could be included. Reaction time was analysed with a two block row (second, third) by two block side (left, right) by two group (pre-crastinators, procrastinators) mixed-design ANOVA. Significant interactions were analysed with simple main effects; the Bonferroni correction was used to control the familywise error rate. Reported values were means and 95% between-participant confidence intervals. An example of these values is 100, [90, 110], where the mean is 100 and the 95% confidence interval is 90–110.

We focused on an overhead, bird's-eye view of the trajectories from the light-emitting diode on the index finger (i.e., movements in the transverse plane). A space-normalised trajectory was calculated for each trial by dividing the

trajectory into 100 points with equally spaced distance. Space-normalised trajectories are useful, because they preserve the movement trajectory (at the expense of some temporal information) when averaged across trials, participants, or both to calculate spatial averages. Grand mean spatial averages and 95% confidence intervals were calculated for the pre- and procrastinators. We compared the same conditions as in the latter reaction time analysis to control for possible confounds. Statistical differences between the spatial averages of pre- and procrastinators occurred when the 95% confidence intervals did not overlap.

Results and discussion

The Pearson correlation coefficient between approach score and probability of choosing the right block revealed the three groups of participants: pre-crastinators ($r \geq 0.29$, n_{pre} = 23), procrastinators ($r \leq -0.29$, n_{pro} = 20), and neither pre-crastinators nor procrastinators ($-0.29 < r < 0.29$, $n_{neither}$ = 9). Pre-crastinators had a mean correlation coefficient of 0.75, [0.67, 0.82]. In addition, procrastinators had a mean correlation coefficient of -0.70, [-0.79, -0.62]. Mean probabilities for different approach scores of pre-crastinators are shown in Fig. 2, left. When the approach score was 0.2 (condition [1,4]), pre-crastinators chose the near, left block more often than the far, right block (p[Right] = 0.15). In contrast, when the approach score was 0.8 (condition [4,1]), pre-crastinators preferred the near, right block (p[Right] = 0.96). Mean probabilities for the range of approach scores of procrastinators are shown in Fig. 2, right. When the approach score was 0.2 (condition [1,4]), procrastinators preferred the far, right block (p[Right] = 0.95). In contrast, when the approach score was 0.8 (condition [4,1]), procrastinators chose the far, left block more often than the near, right block
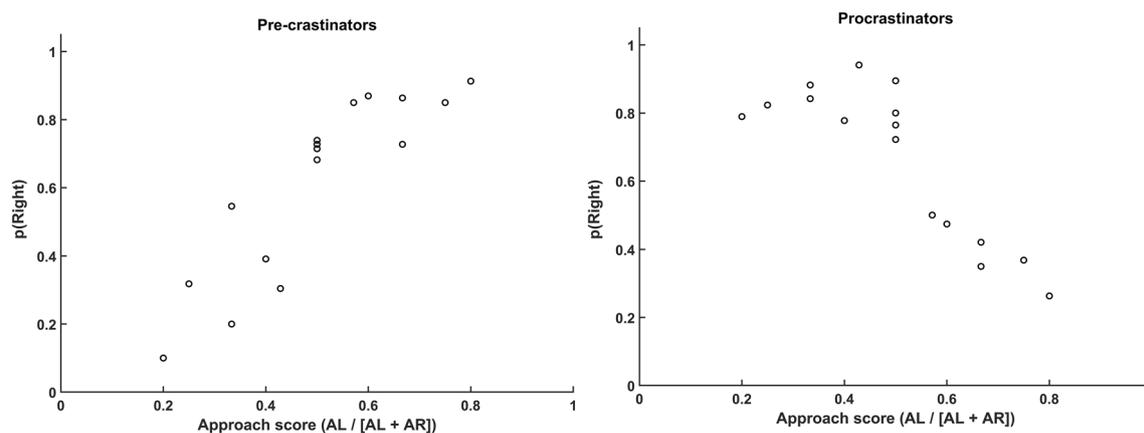
Fig. 3 Probabilities of selecting the right block for the range of approach scores based on the first 16 trials from all pre-crastinators (left) or procrastinators (right). Approach score was calculated as the position of the left block divided by the position of the left block plus the right block

(p[Right] = 0.32). The group that neither pre-crastinated nor procrastinated all had small correlation coefficients, but they had different patterns of approach scores and probabilities. Three participants had a wide range of probabilities that were unrelated to the approach score, whereas three other participants chose the right block at least 86% of the time regardless of approach score.

Note that, for both pre-crastinators and procrastinators, the approach score by probability graphs is slightly bimodal (Fig. 2). For pre-crastinators, for example, probabilities increase gradually from an approach score of 0.20–0.43. Probabilities then have a large increase with an approach score of 0.50. This result suggests that participants have a strong preference for the block on the right when the blocks are in the same positions. Probabilities are then similar for approach scores of 0.57–0.80. These strong preferences for blocks on the right were likely caused by a biomechanical advantage (e.g., Carey et al. 1996) for our predominantly right-handed participants (96% of participants were right handed) to reach from their midline towards their dominant/ipsilateral side.

We were surprised that about 40% of our participants pre-crastinated and 40% procrastinated, especially because Rosenbaum et al. (2014) found only pre-crastinators across multiple experiments with over 200 participants. A potentially important difference between these studies is how probabilities were calculated. In the current study, probabilities were calculated for each participant. This was possible because each participant had eight trials in each of the 16 conditions, a total of 128 trials. In the study by Rosenbaum and colleagues, each participant had one trial in each of the 16 conditions, a total of 16 trials. This made it impossible to calculate probabilities at the participant level. Instead, probabilities were calculated by combining data from all participants. It is possible that all participants pre-crastinated

in the first 16 trials, and then, with repeated exposure, different participants diverged into either pre-crastination or procrastination. We investigated this possibility by replicating Rosenbaum's probability calculations on our data, which was done by including only the first 16 trials for each participant. The results showed no significant change in group behaviour from the first 16 trials to all 128 trials: our original group of pre-crastinators tended to pre-crastinate in their first 16 trials ($r = 0.88$; Fig. 3, left) and our original group of procrastinators tended to procrastinate in their first 16 trials ($r = -0.84$; Fig. 3, right). Our first novel result from Rosenbaum et al. (2014) is, therefore, that many participants did not pre-crastinate. This difference was not caused by how probabilities were calculated. There are, of course, differences in the tasks performed by participants in the two studies. Most notably, our task was a reach-to-grasp task, whereas Rosenbaum's task was primarily a walking task. We will return to discuss how these, and other, differences may have encouraged some participants to procrastinate in the general discussion.

Reaction time in the conditions where the left and right blocks were zero, one, two, or three rows apart were analysed with a one-way repeated-measures ANOVA, which was not significant, $F(3, 126) = 2.0$, $p = 0.124$, $E_{HF} = 0.903$, $n_p^2 = 0.05$. The grand mean reaction time was 393 ms, [368, 418]. Reaction time, therefore, did not depend on the distance between the left and right blocks. We predicted that reaction time would decrease as the distance between blocks increased; for example, reaction time would be shorter when the blocks were three rows apart compared to when they were one row apart. The logic was that choosing a block might be easier when they are farther apart. An easier decision could decrease the demands on information processing and, subsequently, shorten reaction time. The actual results, which reaction time did not depend on the distance between

Table 1 ANOVA table result of the two block row (second, third) by two block side (left, right) by two group (pre-crastinators, procrastinators) on reaction time

|	$F(1,37)$	p value	n_p^2
Block row	0.023	0.890	0.001
Block row × group	0.228	0.636	0.006
Block side	15.014	0.000	0.289
Block side × group	0.900	0.349	0.024
Block row × block side	0.146	0.704	0.004
Block row × block side × group	4.686	0.037	0.112
Group	3.898	0.056	0.095

blocks, suggest the difficulty of choosing a block was comparable in all the conditions. Perhaps, a strategy is selected at the start of the study to either pre- or procrastinate. This strategy persists for the whole study and does not need to be selected de novo for each trial. Preselecting and preserving a strategy may obviate the "decision" on each trial, which would cause comparable reaction time across conditions. Perhaps, the cognitive load, physical effort, or both must exceed a cost threshold on a subsequent trial to overcome the computational savings on response selection to maintain the chosen strategy. The hypothesis that a preselected strategy obviates the decision between blocks does fit with our results, but it is a post hoc explanation that requires confirmation by further experimentation.

Reaction time was further analysed to compare pre- and procrastinators. This was done with a two block row (second, third) by two block side (left, right) by two group (pre-crastinators, procrastinators) mixed-design ANOVA (Table 1). The significant main effect of Block Side suggested that reaction time was shorter for the right side (384 ms, [360, 408]) than the left side (412 ms, [380, 444]). This right-side advantage was likely caused by a biomechanical advantage

(e.g. Carey et al. 1996) for our predominantly right-handed participants (96% of participants were right handed) to reach from their midline towards their dominant/ipsilateral side. The main effect of group was not significant, but the p value was small. Reaction time was shorter for pre-crastinators (371 ms, [335, 407]) than procrastinators (425 ms, [383, 466]).

There was also a significant three-way interaction (Fig. 4), which was analysed with simple main effects on block side and group. Analysis on block side showed that reaction time was shorter for the right side than the left side for three of the four comparisons, ps ≤ 0.018, which was similar to the significant main effect of block side. Reaction time was comparable for the pre-crastination group making reaching movements to the left block or right block in the second row, $p = 0.413$. Analysis on Group suggested that reaction time was shorter for pre-crastinators than procrastinators for two of the four comparisons: blocks on the left side in the second row, $p = 0.047$, and blocks on the right side in the third row, $p = 0.035$. The other two conditions were not significant, but the p values were small, $p ≤ 0.120$.

The most important result from this analysis is that pre-crastinators had significantly shorter reaction time, and thus information processing, than procrastinators for half of the reach-to-grasp movements. We wondered whether there was a relationship between mean reaction time and behaviour of the participants. This was examined by correlating the correlation coefficient of approach score by probability by mean reaction time for all the participants (Fig. 5). There was a significant negative correlation with a medium-effect size, $r = -0.31$, $p = 0.025$. This suggests that participants with relatively short reaction time had large positive correlation coefficients, which are indicative of pre-crastination. And participants with relatively long reaction time had large negative correlation coefficients, which are indicative of procrastination. Interestingly, a similar correlation with mean
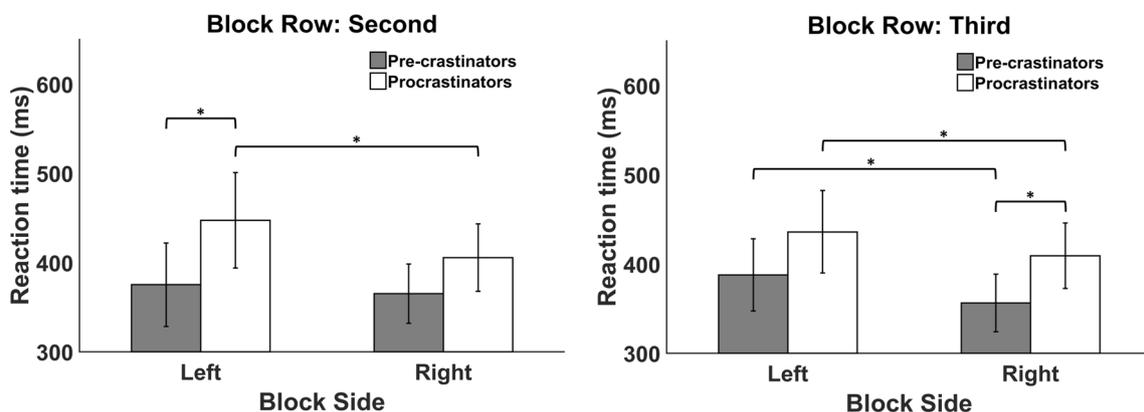
Fig. 4 Reaction time results for the significant two Block Row [second (left figure), third (right figure)] by two Block Side (left, right) by two Group (pre-crastinators, procrastinators) interaction. Error bars are 95% confidence intervals. *$p < 0.05$
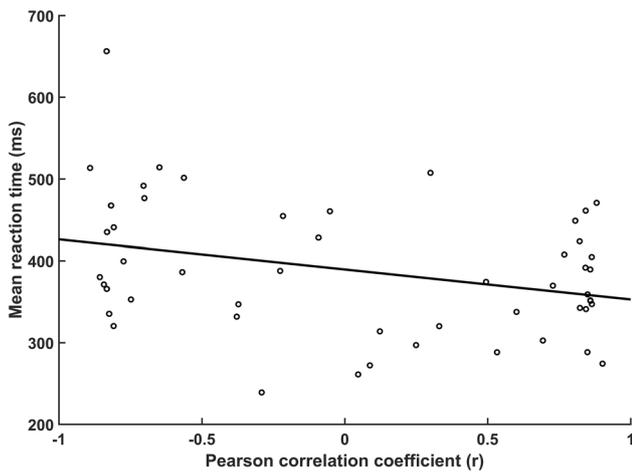
Fig. 5 The correlation coefficient of approach score by probability of selecting the right block (*x*-axis) for each participant plotted by their mean reaction time (*y*-axis). There was a significant negative correlation with a medium-effect size, $r = -0.31$, $p = 0.025$. Approach score was calculated as the position of the left block divided by the position of the left block plus the right block

movement time instead of reaction time was not significant, $r = 0.22$, $p = 0.121$. This suggests that movement time was unrelated to whether a participant pre- or procrastinated.

Our interpretation of the significant relationship between behaviour and reaction time is that the duration of information processing is shorter to pre-crastinate than to procrastinate. The more a participant tends to pre-crastinate, the shorter their reaction time. And, likewise, the more a participant tends to procrastinate, the longer their reaction time. In terms of information processing and cognitive load, it is easier to pre-crastinate than to procrastinate. This finding supports the automatic response selection hypothesis. It

suggests that the duration of information processing to pre-crastinate is short, because one can rely on an automatically selected response. The duration of information processing to procrastinate, in contrast, is long, because one must first inhibit the automatic response to pre-crastinate. This does not mean that participants will always pre-crastinate, as the physical effort to pre- or procrastinate must also be considered and weighed against the cognitive load of that decision. It is also important to note that although there is a significant relationship between correlation coefficient and mean reaction time, we cannot conclude that these variables have a causal relationship. It would be interesting to isolate a group of procrastinators and ask them to shorten their reaction time; would this cause them to switch to pre-crastination?

Recall that participants with a positive correlation with at least a medium-effect size ($r \geq 0.29$) were classified as pre-crastinators, participants with a negative correlation with at least a medium-effect size ($r \leq -0.29$) were classified as procrastinators, and participants with correlation coefficients between these two groups ($-0.29 < r < 0.29$) were classified as neither pre-crastinators nor procrastinators. There are, of course, other ways to divide the groups. We reran the analyses with pre-crastinators defined as having positive correlations ($r > 0$) and procrastinator defined as having negative correlations ($r < 0$). The results were slightly different; most notably, there was a larger difference between reaction time of pre-crastinators and procrastinators. The slightly different results did not alter our conclusions, and, therefore, we argue that the conclusions are fairly robust to how pre-crastinators and procrastinators are defined.

We also analysed spatial averages to compare pre- and procrastinators. The same reach-to-grasp movements were analysed as the latter reaction time analysis. Grand mean spatial averages and 95% confidence intervals for pre- and
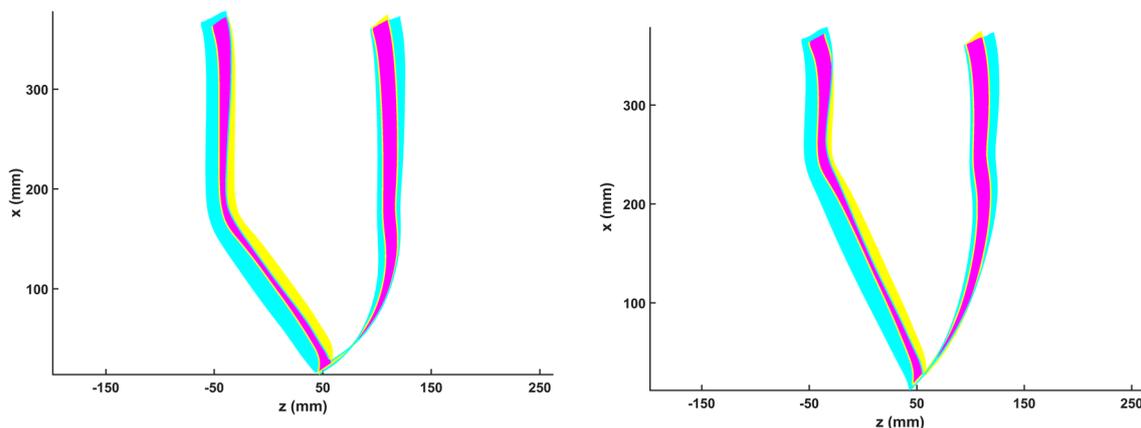
Fig. 6 95% confidence intervals of the spatial averages with pre-crastinators in yellow (light grey), procrastinators in cyan (medium grey), and the overlap between them in magenta (dark grey). The spatial

averages show the entire trajectory from the home position to grasping the block in the second row (left) or the third row (right), and then to placing the block in the fifth row. Colour figure available online

procrastinators to left and right blocks are shown in Fig. 6. Movements to blocks in the second row and third row are shown in Fig. 6, left and right, respectively. Note that the confidence intervals of pre- and procrastinators overlapped for all of movement executions and for all reach-to-grasp movements. This suggested that the trajectories of pre- and procrastinators were not significantly different. Thus, participants had similar trajectories regardless of whether they chose to pre- or procrastinate. In other words, trajectories did not yield any clues as to why some participants chose to pre-crastinate, while others chose to procrastinate.

General discussion

The goal of the current study was to further investigate the mechanisms of the pre-crastination effect, which is the tendency to choose the closer of two targets, even at the expense of extra physical effort. This was done by converting the primarily walking task used by Rosenbaum et al. (2014) to a reach-to-grasp task. This change enabled the measurement of movement trajectories and the duration of information processing when participants decided which block to move. Our first novel finding was that many participants did not pre-crastinate; participants exhibited a range of behaviours: about 40% pre-crastinated, 40% procrastinated, and 20% neither pre-crastinated nor procrastinated. This was surprising, because Rosenbaum et al. (2014) showed a clear preference to pre-crastinate in over 200 participants across multiple experiments. Importantly, this difference was not caused by how probabilities were calculated in these two studies. Three groups of participants emerged regardless of whether probabilities were calculated for each participant or across all the participants in the first 16 trials. This latter method was how probabilities were calculated by Rosenbaum et al. (2014). The pre-crastination effect is at least somewhat robust. It has been observed in walking and reaching tasks that are slightly different from the original study by Rosenbaum and colleagues (Fournier et al. 2018; Potts et al. 2018). The pre-crastination effect has even been shown by pigeons in button-pressing tasks (Wasserman and Brzykey 2015; Zentall et al. 2018).

It is not surprising, in of itself, that humans do not always pre-crastinate. Humans have shown a preference for procrastination when the costs of the task change. We previously mentioned that when the two buckets are of unequal weights, participants prefer the lighter bucket over the closer bucket (Rosenbaum et al. 2014 Experiments 9; Potts et al. 2018, Experiment 2). It has also been shown that the distance required to reach for the bucket affects which bucket is selected. Potts et al. (2018) tested a task that was similar to the task by Rosenbaum et al. (2014), except the buckets required either short- or long-distance reaches (20 or 80% of

arm length). The results suggested that the decision of which bucket to choose was influenced by walking distance and reaching distance. Participants preferred to pre-crastinate and pick up the bucket with a short walking distance, and they also preferred to pick up the bucket with a short reaching distance. These studies show that the pre-crastination effect is not set in stone. As Potts et al. (2018) concluded, "there are limits to the kinds of costs people are willing to incur to complete sub-goals as soon as possible", that is, to pre-crastinate.

What is surprising about the current results is that some participants pre-crastinated, while others did the opposite and procrastinated. The costs in the previous experiments caused all participants to pre-crastinate or all participants to procrastinate. It is also surprising that many of our participants chose to procrastinate when the task was a scaled-down version of the one used by Rosenbaum et al. (2014). The most obvious difference between these tasks is that ours was a reaching task, whereas theirs was primarily a walking task. However, our task was similar in that cognitive load was required to hold the two goals of the task (pick up a block and put it down at the end) and that physical effort was required to reach, grasp, and place the blocks. This task was a scaled-down version, because cognitive load and physical effort were reduced: the task goals were held for a short duration of less than 2 s and reaching and grasping required less energy than walking down the 16-foot alley. It is very likely that the cognitive and physical costs changed when the task was scaled down. This change in costs may be more obvious when the task is scaled up. Potts et al. (2018) gave the example of deciding whether to walk 1 km, pick up a bucket, and then walk 10 km or to walk 10 km, pick up a bucket, and then walk 1 km. The increased physical cost to carry the bucket 10 km would likely cause participants to procrastinate and choose the latter option. Therefore, scaling the difficulty of the task up or down likely changes the cognitive load, physical cost, and their interaction. It is possible that these changes in the current study enabled some participants to pre-crastinate and others to procrastinate. This led us to ask what, besides block selection, differentiated our pre- and procrastinators?

The duration of information processing differentiated our participants; specifically, there was a relationship between duration of information processing and behaviour of participants. Let us first consider that the duration of information processing was unaffected by how far the blocks were apart. In other words, the difficulty of choosing a block was comparable regardless of where the blocks were positioned. We suggested that a strategy to either pre- or procrastinate was selected at the start of the study. Preselecting and preserving this strategy for the entire experiment may obviate the "decision" on each trial and cause comparable durations of information processing across conditions. Similarly,

Fournier et al. (2018) argued that selection of the closer target (that is, pre-crastination) is automatic and does not require thoughtful deliberation. Their reasoning was that perception of objects can either automatically activate the objects' affordances (e.g., Tucker and Ellis 1998) or facilitate object selection (e.g., Craighero et al. 1996). In either case, participants rely on an "automatic response tendency" to select the closer object and pre-crastinate (Fournier et al. 2018). An automatic pre-crastination response is beneficial, because it reduces cognitive load and frees up cognitive resources.

Recall that participants with relatively short durations of information processing tended to pre-crastinate and that participants with relatively long durations tended to procrastinate. The automatic pre-crastination response hypothesis can also explain why it is more difficult to procrastinate. We suggest that participants in all groups automatically selected the closer block to pre-crastinate (the automatic pre-crastination response hypothesis). This automatic selection was then carried out by the group of pre-crastinators. The group of procrastinators, in contrast, inhibited the automatic pre-crastination and then selected the farther block based on their strategy to procrastinate. Of note, Fournier et al. (2018) also suggested that procrastination required inhibition of the automatic response to pre-crastinate. The inhibition of the automatic pre-crastination response by the procrastinators in the current study increased the duration of information processing and likely caused the relationship between the duration of information processing and participant behaviour.

Rosenbaum and colleagues (Fournier et al. 2018; Potts et al. 2018; Rosenbaum et al. 2014) have shown a clear preference for pre-crastination, whereas the present study found that some participants preferred to pre-crastinate, while others preferred to procrastinate. These contrasting results are caused by one or more of the differences in the tasks performed by the participants. Rosenbaum and colleagues used a primarily walking task, where the participant reached with their left arm or right arm to target objects. The task in the current study involved reaching movements with only the dominant arm. The smaller scale of our reaching may have caused the block that was not selected to become an obstacle. Obstacles affect the kinematics of reach-to-grasp movements even when they are not in the normal path of the movement without obstacles (e.g., Mon-Williams et al. 2001; Tresilian 1998; Voudouris et al. 2012). It is possible that our pre-crastinators, who preferred the closer block, were trying to minimise interference from the obstacle in the initial reach-to-grasp movement rather than minimising cognitive load. Likewise, the procrastinators, who preferred the farther block, may have been trying to minimise interference from the obstacle in the subsequent grasp-to-place movement rather than minimising physical effort. One object acting as an obstacle might also explain the other results; for

example, recall that reaction time was shorter and there was an overall preference for blocks on the right. We originally interpreted these findings as a biomechanical advantage for the predominantly right-handed participants to reach towards their dominant/ipsilateral side. The trajectories of ipsilateral reaches also have the benefit of less interference from the obstacle compared to contralateral reaches.

Another difference between tasks is that Rosenbaum and colleagues (Fournier et al. 2018; Potts et al. 2018; Rosenbaum et al. 2014) had one repetition of each condition whereas we had eight repetitions of each condition. Recall that we included multiple repetitions to be able to determine whether each participant pre-crastinated or procrastinated, rather than relying on the overall behaviour of all participants. However, including multiple repetitions might have affected the participants, for example, by increasing fatigue and apathy, by encouraging participants to second-guess their movements and ponder the experimental hypothesis, and/or by causing sequential effects from the previous repetitions of the same condition. We cannot completely rule out these factors, but the data did suggest that the individual tendency to pre-crastinate or procrastinate across all eight repetitions (128 trials) was replicated in the group behaviour after just one repetition (16 trials). We are not arguing that the repetitions had no effect, but, rather, that they did not seem to have a large effect on block selection.

A limitation to this study was our single measurement of cognition via reaction time. Future studies could assess the subjective states of cognition, motivation, and affect with the Dundee Stress State Questionnaire (DSSQ; Langner et al. 2010; Matthews et al. 2002). Of particular interest would be the DSSQ factor of Task Engagement, which assesses whether the participant is enthused and interested in the task or fatigued and apathetic. If procrastination requires an additional inhibition of the automatic pre-crastination response, then the Task Engagement of procrastinators may have a larger decrease than pre-crastinators from the beginning to the end of the study.

In conclusion, how do we decide which object to pick up when faced with two alternatives? Two important factors that can influence decision-making are cognitive load and physical effort. In terms of cognitive load, the present study supports that there is an automatic response to pre-crastinate (Fournier et al. 2018). The automatic response is a preference to begin the first goal as soon as possible, which is beneficial, because it reduces cognitive load. The physical demands of the task must also be considered when deciding which block to choose. If the physical effort required to pre-crastinate becomes onerous, then it is possible to inhibit the automatic response and procrastinate. Cognitive load and physical effort were likely reduced in the current study by using a reach-to-grasp task rather than a primarily walking task. We believe that this change in task demands allowed

some participants to pre-crastinate and others to procrastinate. Participants that chose to pre-crastinate relied on the automatic response and had short durations of information processing. Participants that chose to procrastinate had to inhibit the automatic response, which caused long durations of information processing. Overall, the decision of which block to choose is likely based on many factors and their complex interactions. The literature on the pre-crastination effect has so far considered cognitive load and physical effort. The current study shows that these factors are extremely sensitive to task demands, and so, care must be taken when comparing the results of even seemingly similar tasks. Future studies could expand the pre-crastination effect to situations with more than two alternatives or consider the effect of other factors that influence decision-making.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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

References

Brown SG, Roy EA, Rohr LE, Bryden PJ (2006) Using hand performance measures to predict handedness. Laterality 11(1):1–14

Carey DP, Hargreaves EL, Goodale MA (1996) Reaching to ipsilateral or contralateral targets: within-hemisphere visuomotor processing cannot explain hemispatial differences in motor control. Exp Brain Res 112(3):496–504

Craighero L, Fadiga L, Umiltà CA, Rizzolatti G (1996) Evidence for visuomotor priming effect. Neuroreport 8(1):347–349

Fournier LR, Stubblefield AM, Dyre BP, Rosenbaum DA (2018) Starting or finishing sooner? Sequence preference in object transfer tasks. Psychol Res. https://doi.org/10.1007/s00426-018-1022-7

Klapp ST (1995) Motor response programming during simple and choice reaction time: the role of practice. J Exp Psychol Hum Percept Perform 21(5):1015–1027

Klapp ST (2003) Reaction time analysis of two types of motor preparation for speech articulation: action as a sequence of chunks. J Mot Behav 35(2):135–150

Langner R, Steinborn MB, Chatterjee A, Sturm W, Willmes K (2010) Mental fatigue and temporal preparation in simple reaction-time performance. Acta Psychol 133(1):64–72

Matthews G, Campbell SE, Falconer S, Joyner LA, Huggins J, Gilliland K, Grier R, Warm JS (2002) Fundamental dimensions of subjective state in performance settings: task engagement, distress, and worry. Emotion 2(4):315–340

Mon-Williams M, Tresilian JR, Coppard VL, Carson RG (2001) The effect of obstacle position on reach-to-grasp movements. Exp Brain Res 137(3–4):497–501

Oldfield RC (1971) The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia 9(1):97–113

Potts CA, Callahan-Flintoft C, Rosenbaum DA (2018) How do reaching and walking costs affect movement path selection? Exp Brain Res 236:2727–2737

Richter M (2015) Commentary: Pre-crastination: hastening subgoal completion at the expense of extra physical effort. Front Psychol 6:1269

Rosenbaum DA, Gong L, Potts CA (2014) Pre-crastination: hastening subgoal completion at the expense of extra physical effort. Psychol Sci 25(7):1487–1496

Stone KD, Bryant DC, Gonzalez CLR (2013) Hand use for grasping in a bimanual task: evidence for different roles? Exp Brain Res 224(3):455–467

Tresilian JR (1998) Attention in action or obstruction of movement? A kinematic analysis of avoidance behavior in prehension. Exp Brain Res 120(3):352–368

Tucker M, Ellis R (1998) On the relations between seen objects and components of potential actions. J Exp Psychol Hum Percept Perform 24(3):830

Voudouris D, Smeets JBJ, Brenner E (2012) Do obstacles affect the selection of grasping points? Hum Mov Sci 31(5):1090–1102

Wasserman EA, Brzykcy SJ (2015) Pre-crastination in the pigeon. Psychon Bull Rev 22(4):1130–1134

Zentall TR, Case JP, Andrews DM (2018) Procrastination in the pigeon: can conditioned reinforcement increase the likelihood of human procrastination? Psychon Bull Rev 25(5):1952–1957

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