Following affirmative and negated rules

Supplement

Content:

Supplementary Results for the Main Experiment

The setup of the experiment allows us to measure various variables (see Wirth et al., 2020 for an overview). We report IT and AUC in the main text, as they highlight the spatio-temporal dynamics during practice. Still, we decided to report more DVs in the supplement to give readers a broader overview of participants' behavior.

We will give a short description of each DV, followed by the statistical analysis. After preprocessing and data selection (see main text), all DVs were analyzed in a 2×10 analysis of variance with rule condition and block as within-subject factors. To avoid violations of the sphericity assumption, we used the multivariate approach for all analyses. Planned post-hoc tests probed for the effect of rule condition separately in each block via *t*-tests. In post-hoc analyses, we computed $d_z = \frac{t}{\sqrt{n}}$ and $\Delta = DV_{negated} - DV_{affirmative}$.

SAs (Starting Angles)

SAs (Figure S1) reflect the angle at which a movement is initiated. They are measured against the vertical midline, positive values indicate an initial movement directed at the correct target area, zero indicates an initial movement straight up, and negative values indicate an initial movement towards the incorrect target area.

Starting angles produced neither main effect nor interaction, *Fs*<1.32, *ps*>.241.

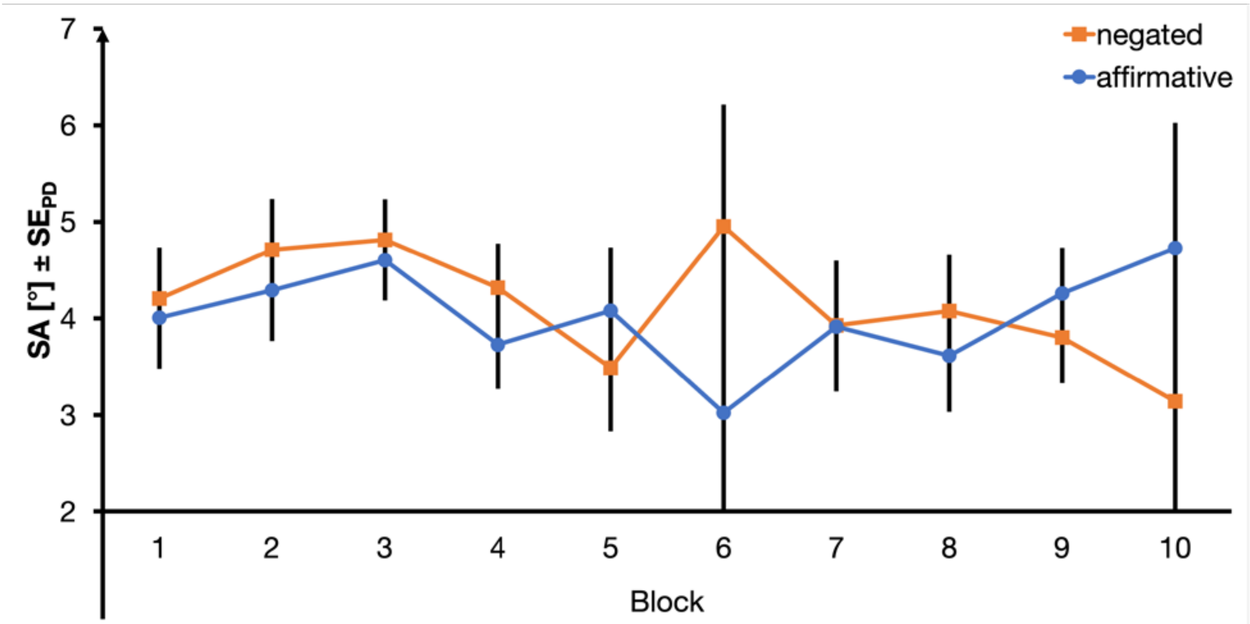

Figure S1. Starting angle (SA) results. Mean SAs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

MTs (Movement Times)

MTs (Figure S2) reflect the time of movement execution. They are measured from the time when the starting area is left until the target area is entered.

A significant effect of rule condition, $F(1,95)=8.55$, $p=.004$, $\eta_p^2=.08$, indicated faster response execution for affirmative rules (536ms) than for negated rules (581ms). Further, a significant contribution of block, $F(9,87)=14.02$, $p<.001$, $\eta_p^2=.59$, showed faster response execution in later blocks (Block 1: 625ms; Block 10: 529ms), producing a significant linear trend, $F(1,95)=64.56$, $p<.001$, $\eta_p^2=.41$. There was no interaction between both factors, $F<1$. Planned post-hoc analyses demonstrated significant negation effects for all blocks, ts>1.66, ps<.049, d_zs>0.17, Δs>32ms.

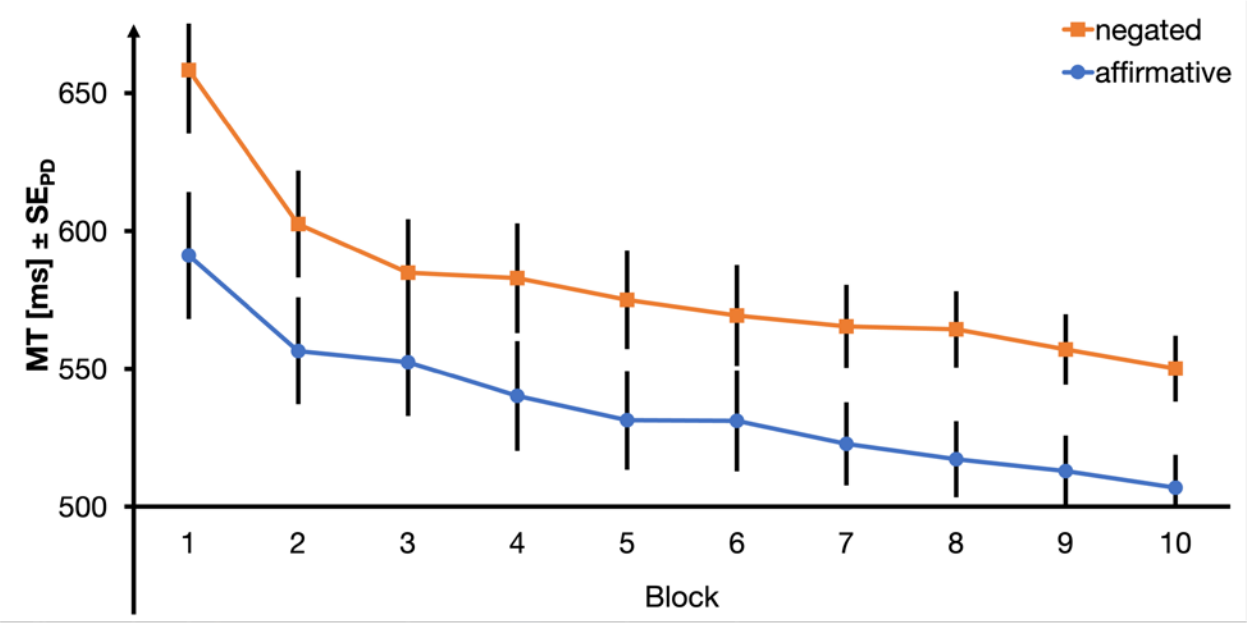

Figure S2. Movement time (MT) results. Mean MTs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

CTs (Click Times)

CTs (Figure S3) reflect the time of movement finalization. They are measured from the time when the target area is entered to when the finger is lifted from the screen.

There was no effect of rule condition, $F<1$. A significant contribution of block, $F(9,87)=7.59$, $p<.001$, $\eta_p^2=.44$, showed faster response finalization in later blocks (Block 1: 185ms; Block 10: 156ms), producing a significant linear trend, $F(1,95)=47.43$, $p<.001$, $\eta_p^2=.33$. There was no interaction between both factors, $F<1$. Planned post-hoc analyses demonstrated significant negation effects for no blocks, $ts<1$.

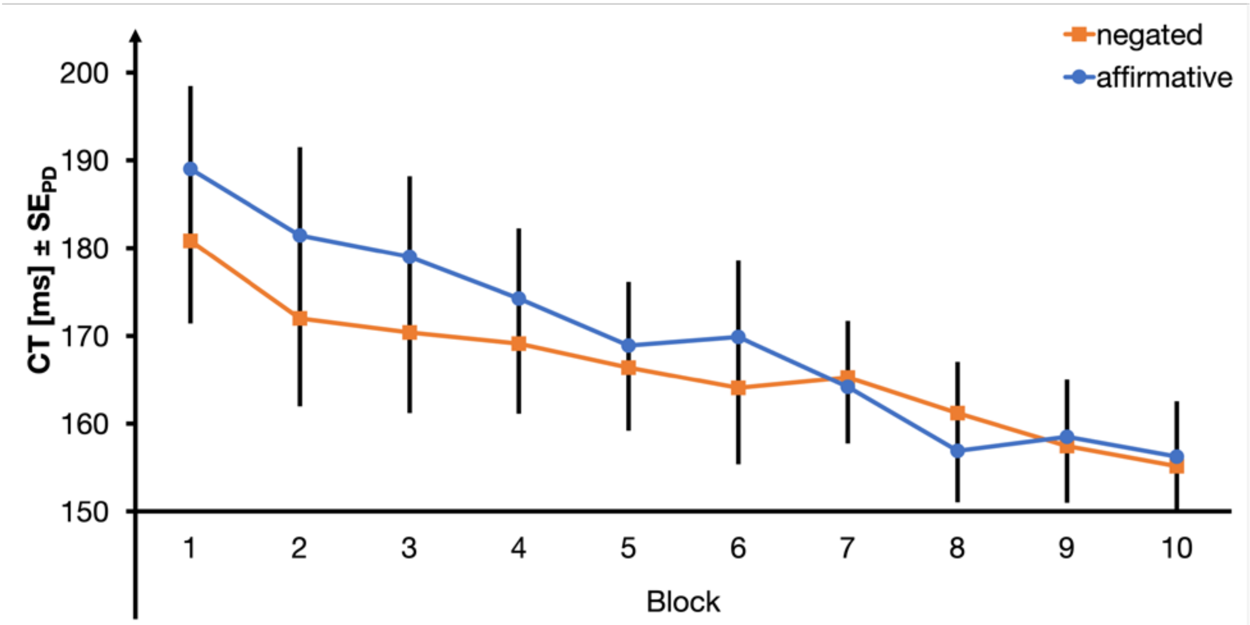

Figure S3. Click time (CT) results. Mean CTs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

MinX (Minimum X)

MinX (Figure S4) reflects the maximum deviation in the incorrect direction in the dimension of the x-axis. More negative values indicate a greater deviation to the incorrect target area and larger ironic effects.

A significant effect of rule condition, $F(1,95)=29.65$, $p<.001$, $\eta_p^2=.24$, indicated smaller deviations for affirmative rules (-14px) than for negated rules (-20px). Further, a significant contribution of block, $F(9,87)=3.05$, $p=.003$, $\eta_p^2=.24$, showed more extreme deviations in later blocks (Block 1: -15px; Block 10: -19px). There was no interaction between both factors, $F<1$. Planned post-hoc analyses demonstrated significant negation effects for all blocks, ts>2.34, ps<.011, d_zs>0.24, Δs>4px.

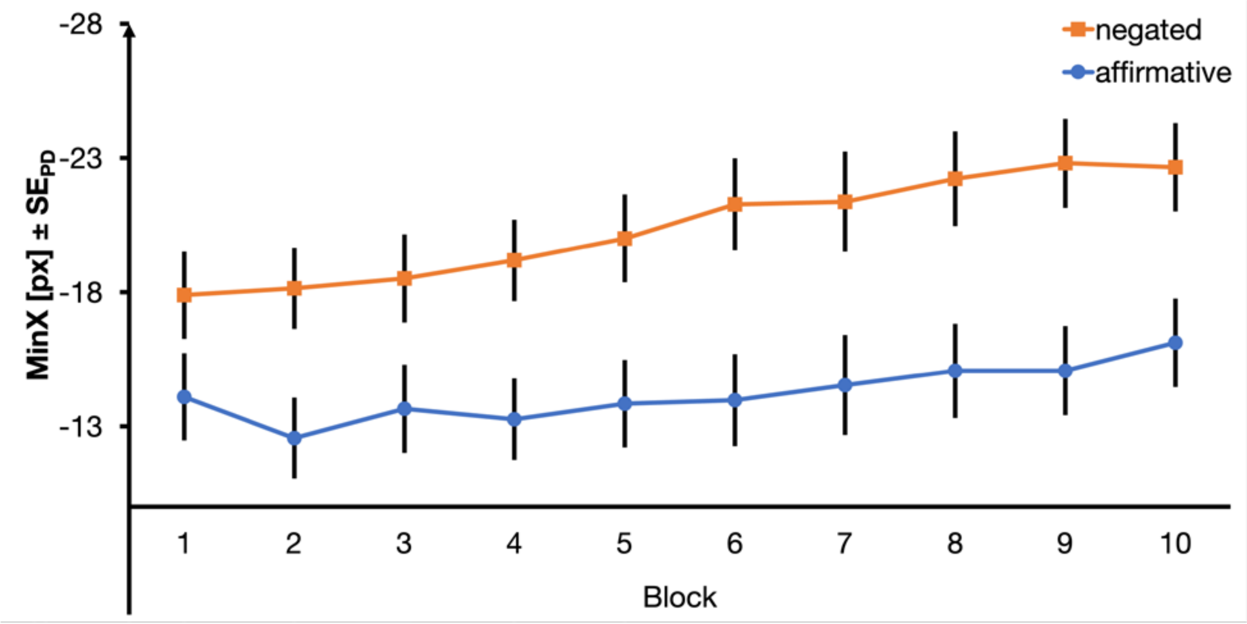

Figure S4. Minimum X (MinX) results. Mean MinX are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

FDT (Final Distance to Target)

FDT (Figure S5) reflects the distance of the final coordinate of the movement to the center of the target area. It gives a measure of spatial precision at the end of the movement.

Final distance to target produced neither main effect nor interaction, *Fs*<1.64, *ps*>.117.

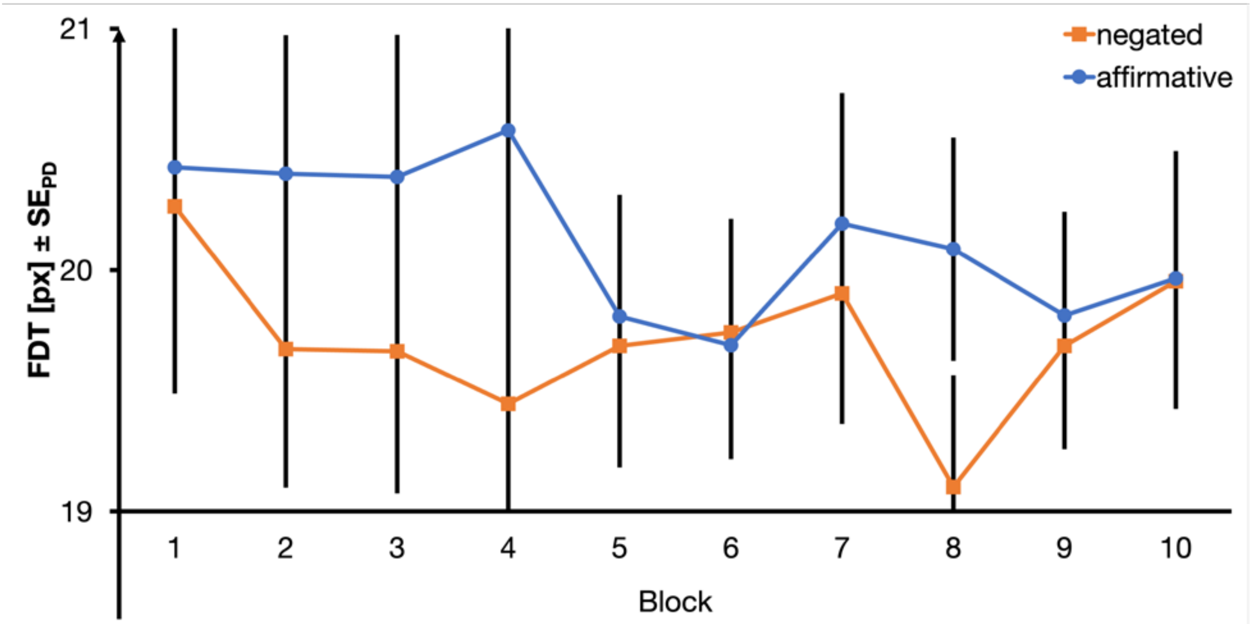

Figure S5. Final distance to target (FDT) results. Mean FDTs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

xFlips (x-Flips)

xFlips (Figure S6) reflect the number of times that the direction of the movement is changed in the dimension of the x-axis. More xFlips indicate less direct movements.

A significant effect of rule condition, $F(1,95)=40.69$, $p<.001$, $\eta_p^2=.30$, indicated less directional changes for affirmative rules (1.04flips) than for negated rules (1.15flips). There was neither a contribution of block nor and interaction between both factors, $F<1$. Planned post-hoc analyses demonstrated significant negation effects for all blocks, ts>2.29, ps<.012, d_zs>0.23, Δs>0.07flips.

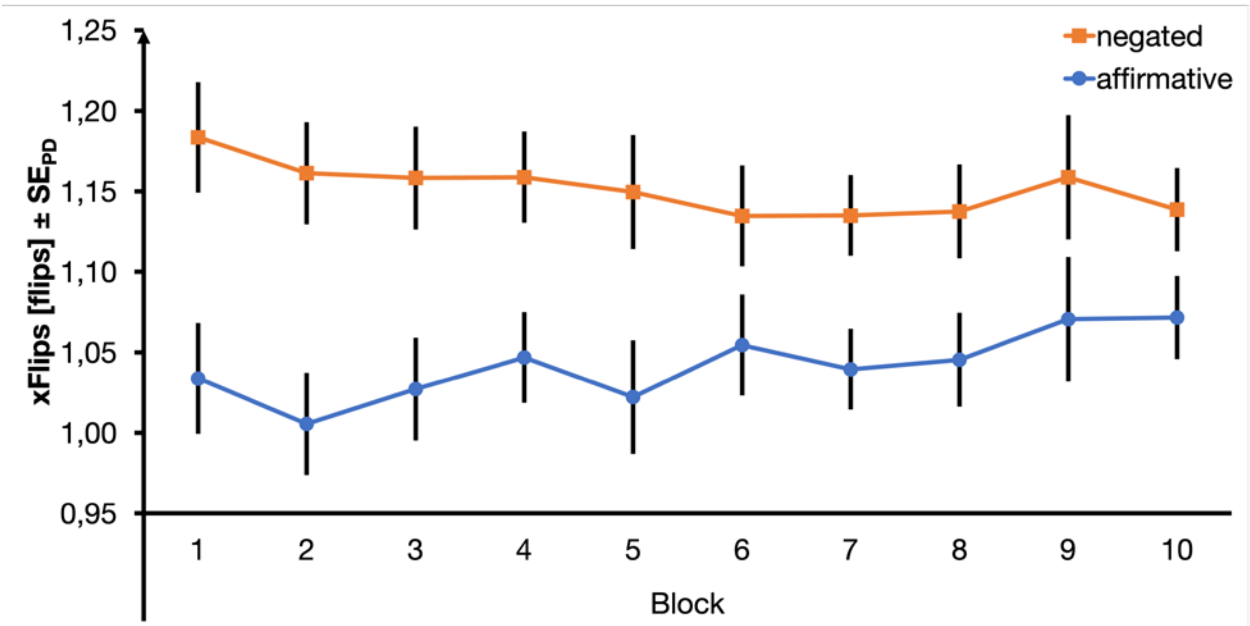

Figure S6. x-Flips (xFlips) results. Mean xFlips are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

ENT (Entropy)

Entropy (Figure S7) reflects movement complexity by analyzing directional changes on a local scale.

A significant effect of rule condition, $F(1,95)=36.90$, $p<.001$, $\eta_p^2=.28$, indicated less complex movements for affirmative rules (.0288) than for negated rules (.0325). Further, a significant contribution of block, $F(9,87)=2.57$, $p=.011$, $\eta_p^2=.21$, showed more complex movements in later blocks (Block 1: .0304; Block 10: .0325), producing a significant linear trend, $F(1,95)=13.02$, $p<.001$, $\eta_p^2=.12$. There was no interaction between both factors, $F<1$. Planned post-hoc analyses demonstrated significant negation effects for all blocks, ts>2.33, ps<.011, d_zs>0.24, Δs>.0029.

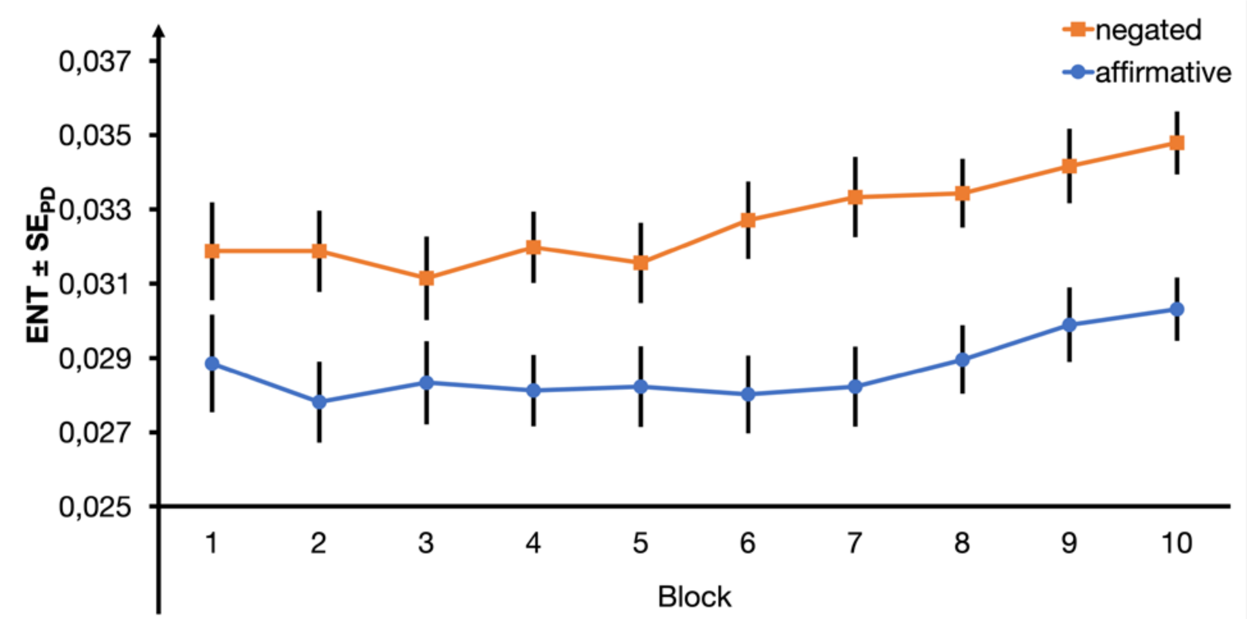

Figure S7. ENT (Entropy) results. Mean ENTs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

MAD (Maximum Absolute Distance)

MAD (Figure S8) reflects the maximal absolute deviation of the movement trajectory to the ideal movement, which would be a straight line from start to end. Larger MADs stand for stronger ironic effects of negations.

A significant effect of rule condition, $F(1,95)=31.07$, $p<.001$, $\eta_p^2=.25$, indicated less spatial deviation for affirmative rules (84px) than for negated rules (100px). Further, a significant contribution of block, $F(9,87)=2.35$, $p=.020$, $\eta_p^2=.20$, showed less direct movements in later blocks (Block 1: 91px; Block 10: 99px), producing a significant linear trend, $F(1,95)=11.48$, $p=.001$, $\eta_p^2=.11$. There was no interaction between both factors, $F<1$. Planned post-hoc analyses demonstrated significant negation effects for all blocks, ts>4.59, ps<.002, d_zs>0.47, Δs>15px.

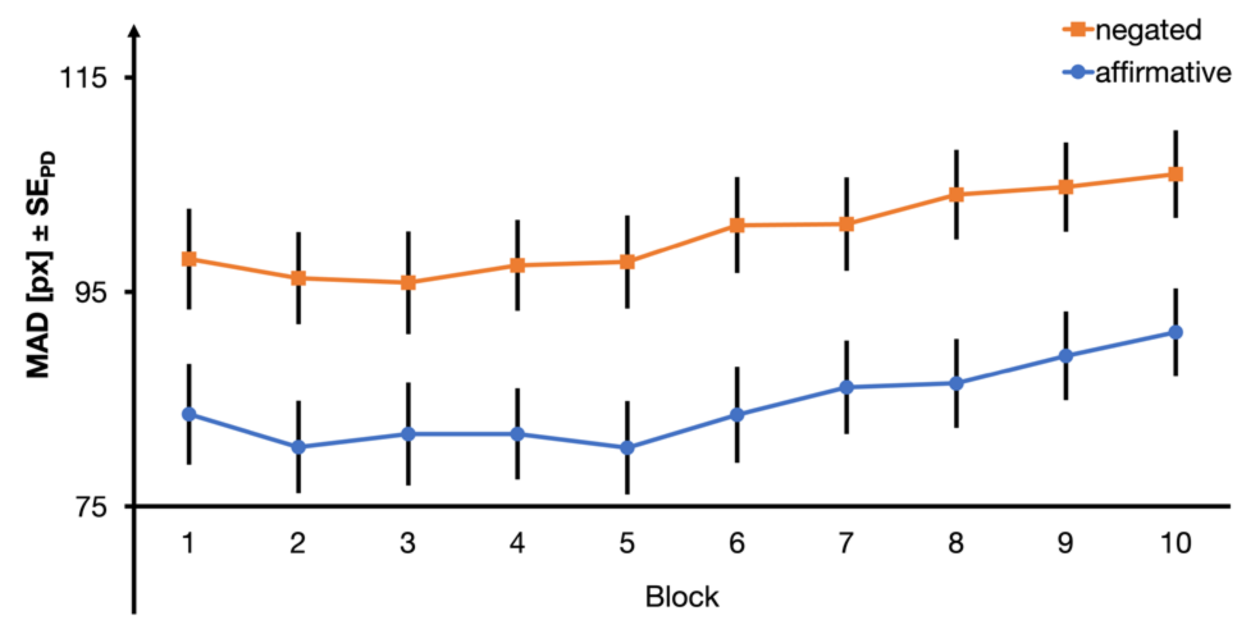

Figure S8. MAD (Maximum Absolute Distance) results. Mean MADs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

Curv (Curvature)

Curv (Figure S9) reflects the ratio of the length of the movement trajectory and the length of the straight line from start to end. Larger values stand for more curved trajectories and larger ironic effects.

A significant effect of rule condition, $F(1,95)=32.62$, $p<.001$, $\eta_p^2=.26$, indicated less curved movements for affirmative rules (1.02) than for negated rules (1.03). There was neither a contribution of block nor and interaction between both factors, Fs<1.83, ps>.074. Planned post-hoc analyses demonstrated significant negation effects for all blocks, ts>3.06, ps<.001, d_zs>0.31, Δs>0.008.

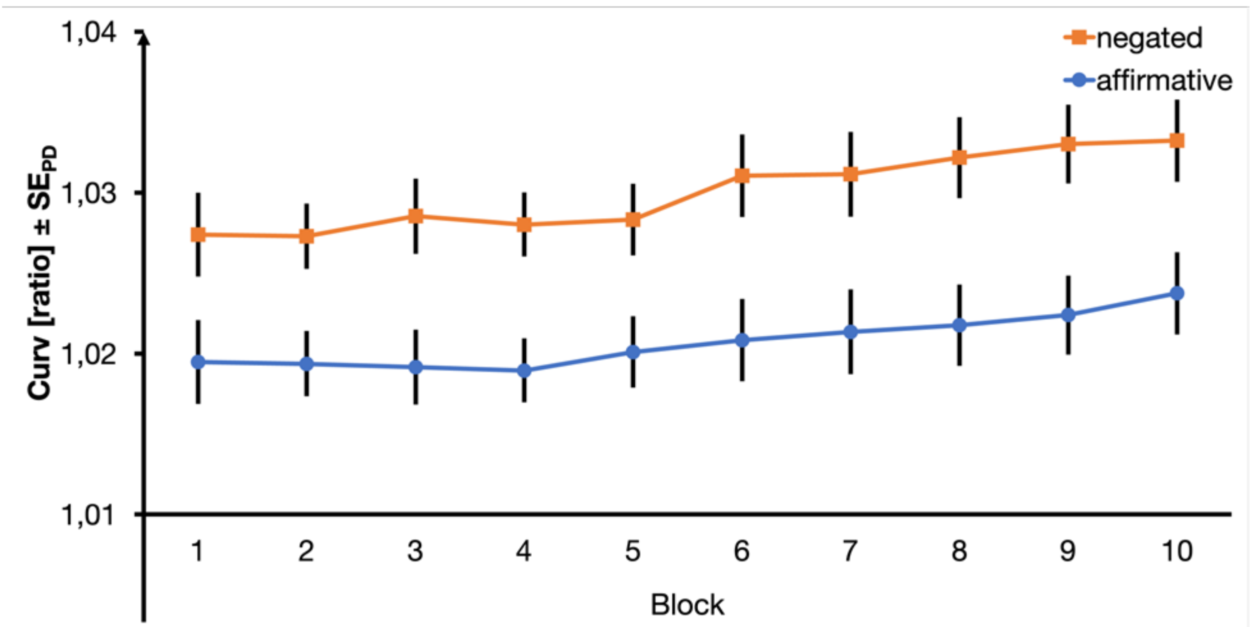

Figure S9. Curv (Curvature) results. Mean Curvs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

TTPV (Time to Peak Velocity)

TTPV (Figure S10) reflects the time (in % movement) at which the peak velocity of the movement is reached.

A significant effect of rule condition, $F(1,95)=49.20$, $p<.001$, $\eta_p^2=.34$, indicated earlier peak velocity for affirmative rules (49.0%) than for negated rules (51.4%). There was neither a contribution of block nor and interaction between both factors, *F*s<1.71, *p*s>.094. Planned post-hoc analyses demonstrated significant negation effects for all blocks, *t*s>2.99, *p*s<.003, d_zs>0.31, Δs>1.5%.

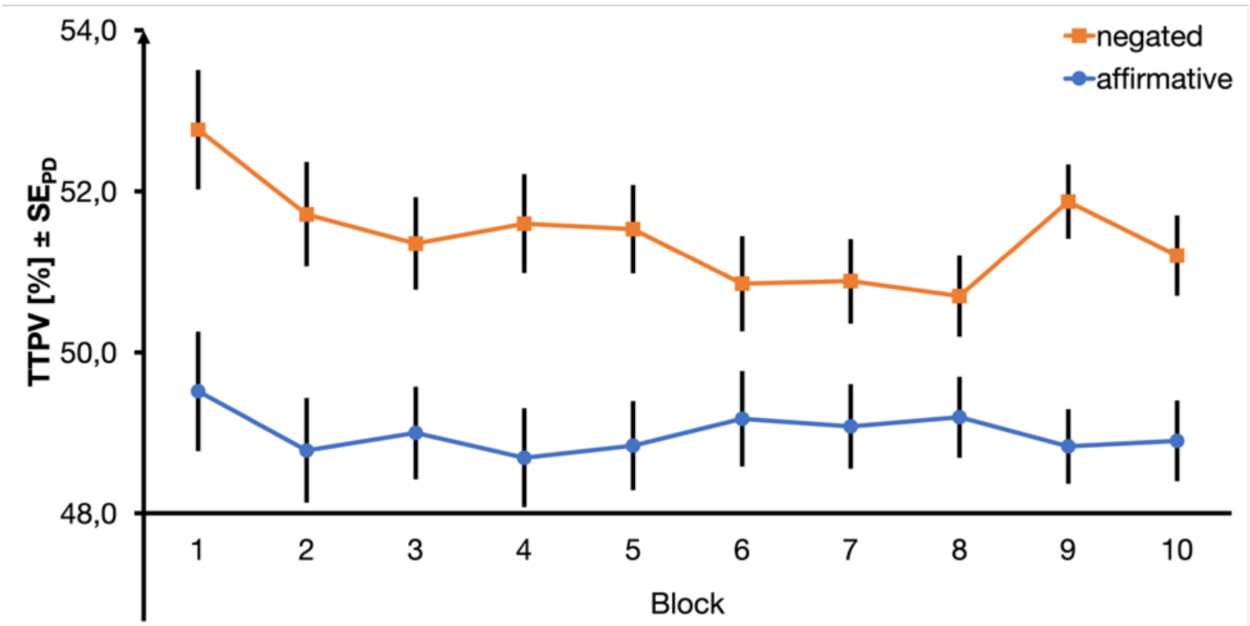

Figure S10. TTPV (Time to Peak Velocity) results. Mean TTPVs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

TTPA (Time to Peak Acceleration)

TTPV (Figure S11) reflects the time (in % movement) at which the peak acceleration of the movement is reached.

A significant effect of rule condition, $F(1,95)=52.71$, $p<.001$, $\eta_p^2=.36$, indicated earlier peak acceleration for affirmative rules (39.8%) than for negated rules (42.5%). Further, a significant contribution of block, $F(9,87)=3.36$, $p=.001$, $\eta_p^2=.26$, showed earlier peak acceleration in later blocks (Block 1: 42.8%; Block 10: 40.6%), producing a significant linear trend, $F(1,95)=15.00$, $p<.001$, $\eta_p^2=.14$. There was no interaction between both factors, $F<1$. Planned post-hoc analyses demonstrated significant negation effects for all blocks, ts>3.40, ps<.001, d_zs>0.35, Δs>2.0%.

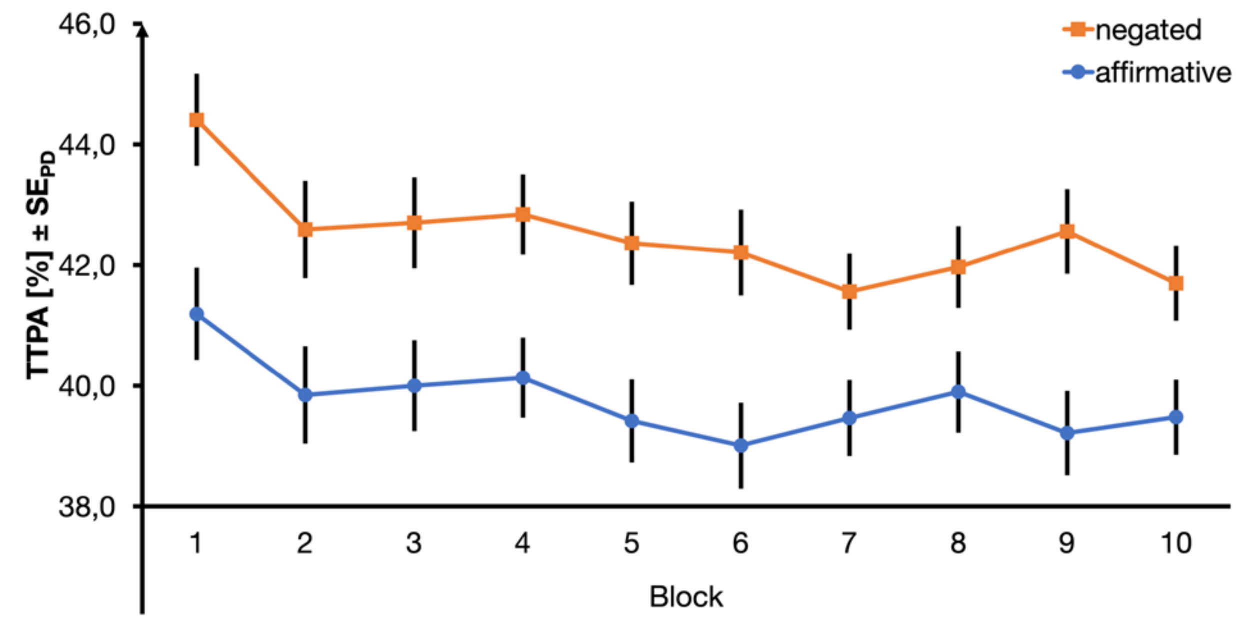

Figure S11. TTPA (Time to Peak Acceleration) results. Mean TTPAs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

Control Experiment

Introduction

The experiment addressed the following potential confounds of the main experiment. We thank two anonymous reviewers for pointing us in this direction.

(a) In the main experiment, the relevant symbol that had to be reached (affirmative rule) or not reached (negated rule) was constant for each participant. This may have led to strategic influences or possible recoding. Even though each stimulus set consisted of three symbols so that easy recoding strategies could be excluded, participants may have come up with more elaborate strategies during the experiment. In the control experiment, the currently relevant symbol could change from trial to trial.

(b) In the main experiment, there were separate symbol set for the two rule types (astrology vs. card symbols). This was done to avoid possible carryover effects. But it may have given participants a shortcut around negation processing, as the type of symbol in the instruction may have indicated what to do. For example, "if the instruction shows an astrology symbol, go to that symbol". "If the instructions shows a card symbol, go to the other symbol" (even though "the other symbol" is not clearly specified here, and in our opinion would entail a negation, i.e., the symbol that is not in the instruction). The control experiment now uses the same symbols for both rule types to eliminate this possible shortcut.

(c) In the main experiment, rule types were blocked and varied between experimental halves. This was done to address the question whether and how repeated enactment of the same rule may lead to pragmatic licensing in case of negated rules. But this may also have led to strategic or motivational influences. The control experiment now varied rule types within a block from trial to trial.

(d) In the main experiment, the instruction between trials (e.g., “to ♈” for affirmative rules; “not to ♠” for negated rules) and the target areas during the trials used the same symbols, i.e., they were both pictorial. This may have led to visual priming effects between instruction and target. In the control experiment, instructions were now written out (e.g., “to spade” for affirmative rules; “not to diamond” for negated rules) while the target areas during the trial were still pictorial.

The control experiment allowed us to rule out these possible alternative explanations by replicating the findings of the main experiment.

Methods

A new set of 48 participants was recruited (mean age=23.9 years, SD=4.4) and fulfilled the same criteria as in the original experiment. This allowed for a power of 1-β > 0.9 for the main effect of rule condition on AUCs as observed in the main experiment ($d_z = \sqrt{24.40}/\sqrt{96} = 0.50$), The experiment was identical to the original experiment with the following changes: There was only one stimulus set (only card symbols: ♠ ♣ ♦) that was used for both affirmative and negated rules. The symbol that participants had to (not) reach was no longer constant across the experiment, but could change from trial to trial. Also, affirmative and negated instructions were no longer separated into distinct blocks, but were also randomly varied from trial to trial. Instructions between trials were changed so that they spelled out the required response so eliminate the pictorial depiction (i.e., “(not) to spade”).

There were still 10 blocks, now consisting of 96 trials, with each combination of two symbols (3 combinations), symbol location (e.g., ♠ ♣ vs. ♣□ ♠□), instruction (affirmative vs. negated), and required response (left vs. right) presented four times.

Results

Preprocessing was done as in the original experiment. We omitted trials in which participants failed to enact the instruction and landed on the wrong target area (0.6%, with no difference between rule conditions, $t(47)=1.46$, $p=.152$), and trials in which participants failed to hit any of the target areas at all (2.5%, with no difference between rule conditions, $|t(47)|<1$). Trials were discarded as outliers if the main measures (IT, AUC) deviated more than 2.5 SDs from a participant's individual cell mean (5.4%). Data for each measure was then aggregated separately for each participant and each combination of rule condition (affirmative vs. negated) and block (1-10). Analyses were conducted as in the original experiment.

ITs (Initiation times)

See Figure S12. A significant effect of rule condition, $F(1,47)=53.70$, $p<.001$, $\eta_p^2=.53$, indicated faster response initiation for affirmative rules (374ms) than for negated rules (445ms). Further, a significant contribution of block, $F(9,39)=5.75$, $p<.001$, $\eta_p^2=.57$, showed faster response initiation in later blocks (Block 1: 486ms; Block 10: 356ms), producing a significant linear trend, $F(1,47)=43.32$, $p<.001$, $\eta_p^2=.48$. There was no interaction between both factors, $F(9,39)=1.93$, $p=.077$, $\eta_p^2=.31$. Planned post-hoc analyses demonstrated significant negation effects for all blocks, ts>4.91, ps<.001, d_zs>0.71, Δs>52ms.

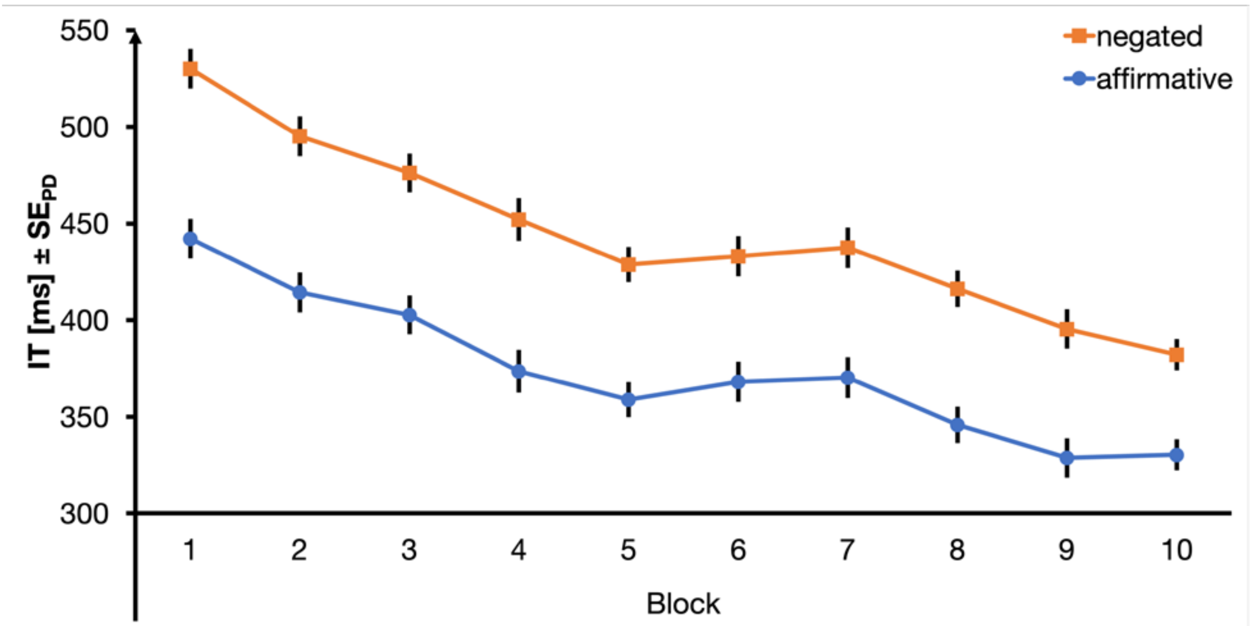

Figure S12. Initiation time (IT) results. Mean ITs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

AUCs (Areas under the Curve)

See Figure S13. A significant effect of rule condition, $F(1,47)=154.67$, $p<.001$, $\eta_p^2=.77$, indicated more direct responses for affirmative rules ($84343px^2$) than for negated rules ($109021px^2$). A significant contribution of block, $F(9,39)=3.50$, $p=.003$, $\eta_p^2=.44$, showed less direct response execution of later blocks (Block 1: $84669px^2$; Block 10: $105234px^2$), producing a significant linear trend, $F(1,95)=8.60$, $p=.004$, $\eta_p^2=.08$. There was no interaction between both factors, $F(9,39)=2.01$, $p=.064$, $\eta_p^2=.32$. Planned post-hoc analyses demonstrated significant negation effects for all blocks, ts>6.47, ps<.001, d_zs>0.93, Δs>$18883px^2$.

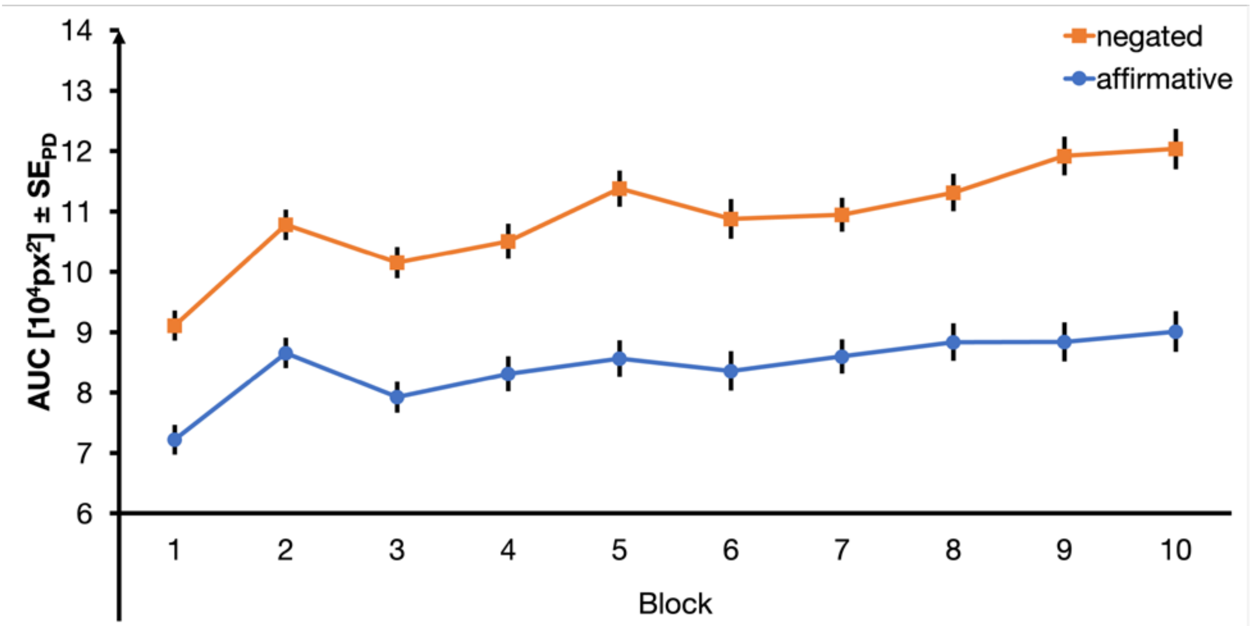

Figure S13. Area under the Curve (AUC) results. Mean AUCs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

SAs (Starting Angles)

See Figure S14. A significant effect of rule condition, $F(1,47)=10.51$, $p=.002$, $\eta_p^2=.19$, indicated more direct movement initiation for affirmative rules (1.04flips) than for negated rules (1.15flips). There was neither a contribution of block nor and interaction between both factors, $Fs<1.79$. Planned post-hoc analyses demonstrated inconsistent results.

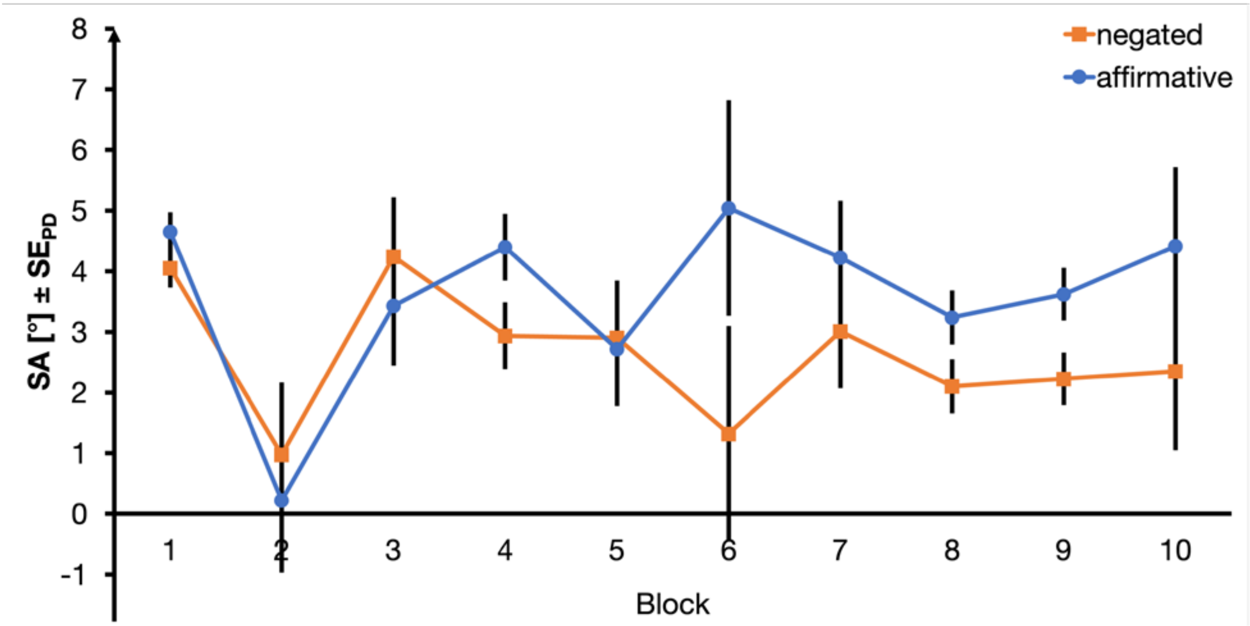

Figure S14. Starting angle (SA) results. Mean SAs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

MTs (Movement Times)

See Figure S15. A significant effect of rule condition, $F(1,47)=118.79$, $p<.001$, $\eta_p^2=.72$, indicated faster response execution for affirmative rules (561ms) than for negated rules (662ms). Further, a significant contribution of block, $F(9,39)=3.66$, $p=.002$, $\eta_p^2=.46$, showed faster response execution in later blocks (Block 1: 681ms; Block 10: 576ms), producing a significant linear trend, $F(1,47)=20.00$, $p<.001$, $\eta_p^2=.30$. There was no interaction between both factors, $F=1.89$, $p=.102$. Planned post-hoc analyses demonstrated significant negation effects for all blocks, ts>6.74, ps<.001, d_zs>0.97, Δs>84ms.

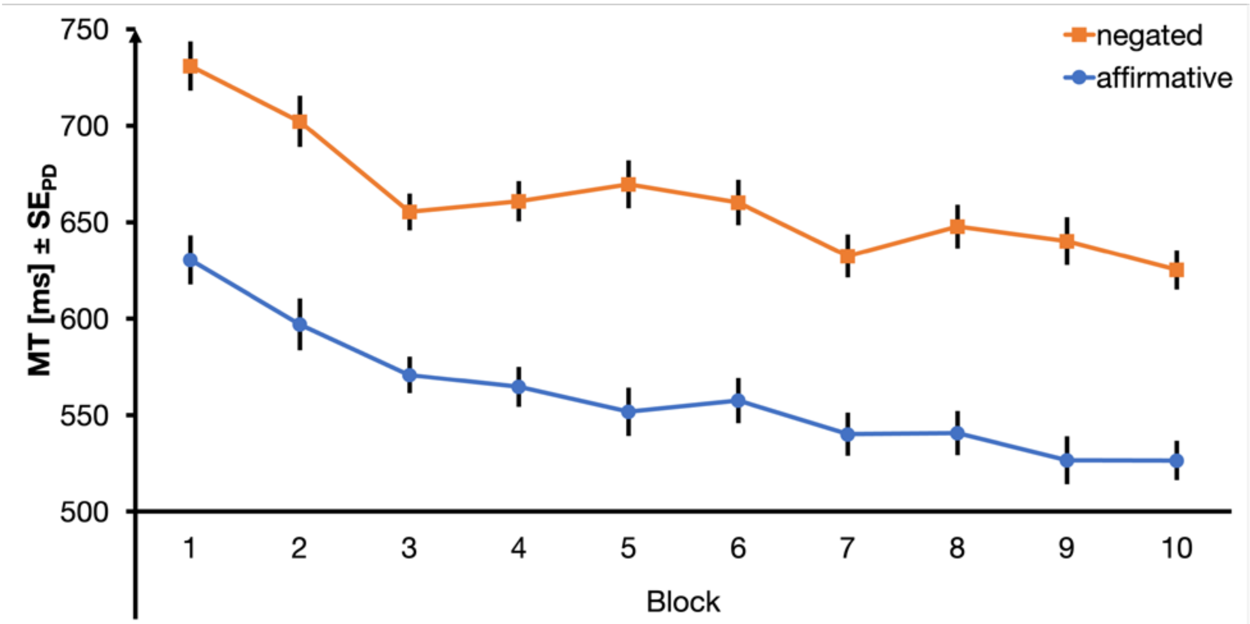

Figure S15. Movement time (MT) results. Mean MTs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

CTs (Click Times)

See Figure S16. A significant effect of rule condition, $F(1,47)=17.57$, $p<.001$, $\eta_p^2=.27$, indicated faster response finalization for affirmative rules (125ms) than for negated rules (128ms). Further, a significant contribution of block, $F(9,39)=5.31$, $p<.001$, $\eta_p^2=.55$, showed faster response finalization in later blocks (Block 1: 154ms; Block 10: 112ms), producing a significant linear trend, $F(1,47)=44.20$, $p<.001$, $\eta_p^2=.49$. There was no interaction between both factors, $F=1.24$, $p=.299$. Planned post-hoc analyses demonstrated inconsistent results.

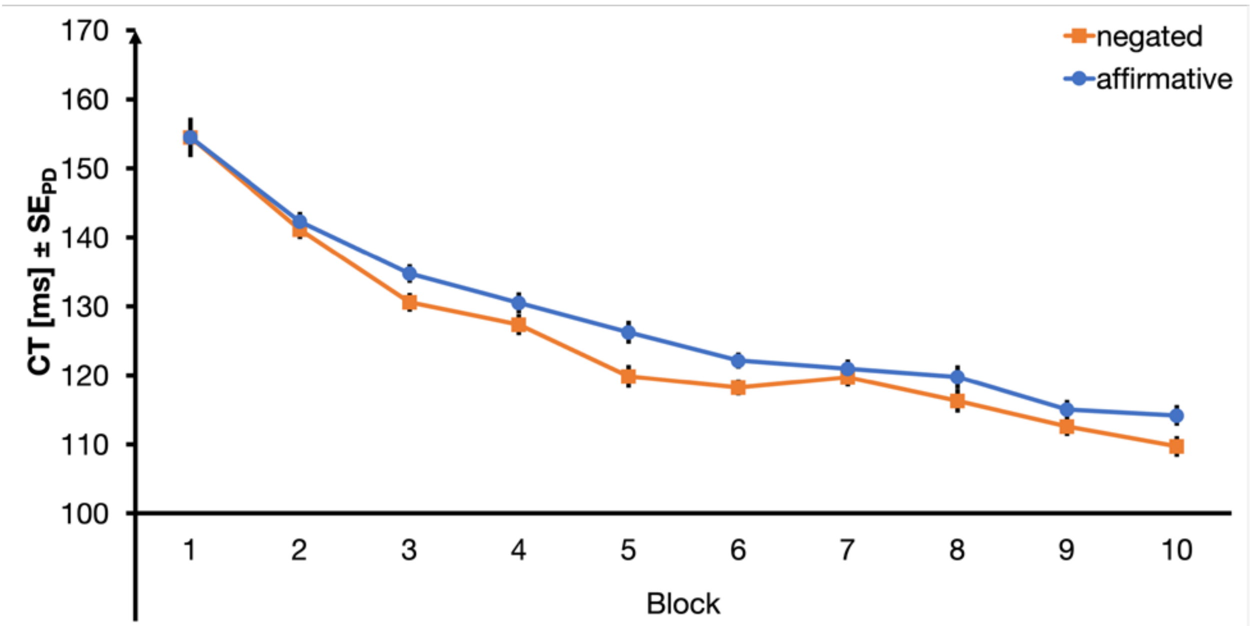

Figure S16. Click time (CT) results. Mean CTs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

MinX (Minimum X)

See Figure S17. A significant effect of rule condition, $F(1,47)=95.43$, $p<.001$, $\eta_p^2=.67$, indicated smaller deviations for affirmative rules (-24px) than for negated rules (-40px). Further, a significant contribution of block, $F(9,39)=3.58$, $p=.003$, $\eta_p^2=.45$, showed more extreme deviations in later blocks (Block 1: -24px; Block 10: -37px), producing a significant linear trend, $F(1,47)=19.99$, $p<.001$, $\eta_p^2=.30$. There was no interaction between both factors, $F=1.85$, $p=.090$. Planned post-hoc analyses demonstrated significant negation effects for all blocks, ts>5.11, ps<.001, d_zs>0.74, Δs>11px.

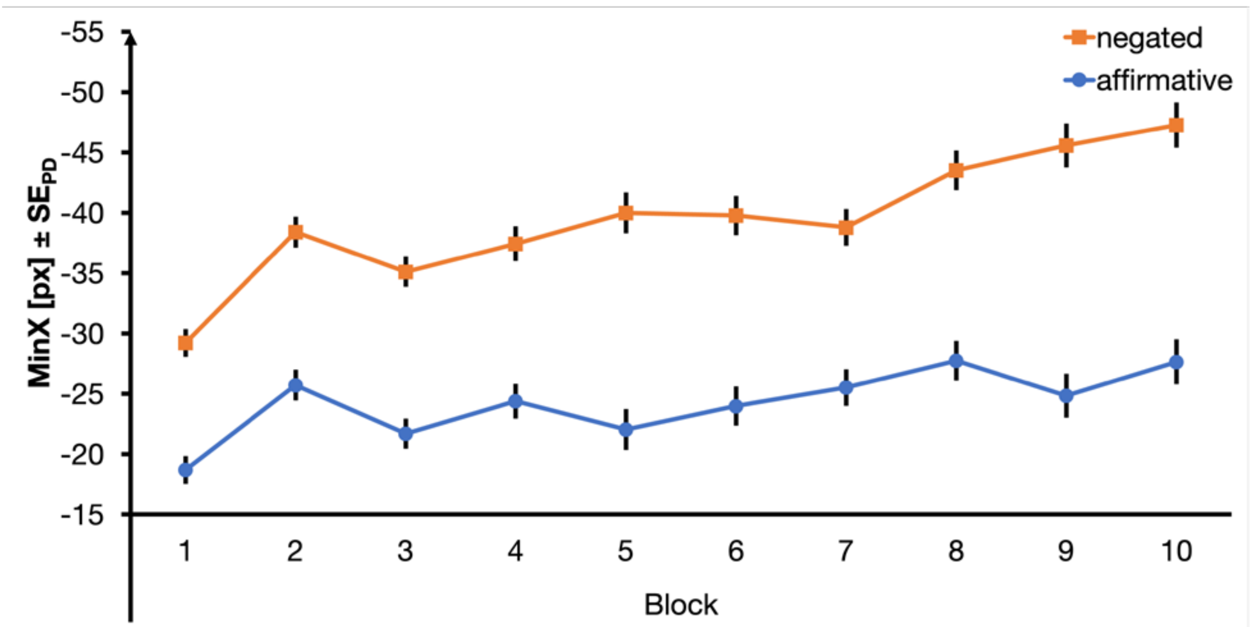

Figure S17. Minimum X (MinX) results. Mean MinX are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

FDT (Final Distance to Target)

See Figure S18. There was a significant contribution of block, $F(9,39)=3.64$, $p=.002$, $\eta_p^2=.46$, with more accurate responses in later blocks (Block 1: -23px; Block 10: -21px). No other effects were significant, $Fs<1.16$, $ps>.287$.

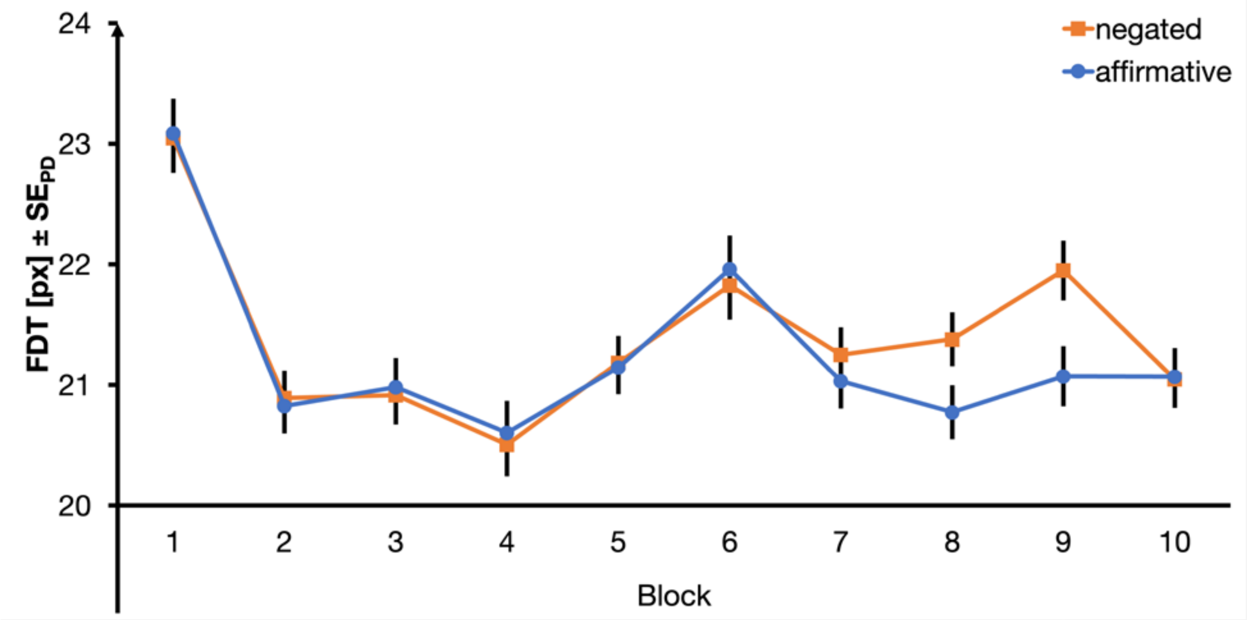

Figure S18. Final distance to target (FDT) results. Mean FDTs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

xFlips (x-Flips)

See Figure S19. A significant effect of rule condition, *F*(1,47)=192.97, *p*<.001, η_p^2=.80, indicated less directional changes for affirmative rules (1.11flips) than for negated rules (1.35flips). There was neither a contribution of block nor and interaction between both factors, *F*s<1.47, *p*s>.193. Planned post-hoc analyses demonstrated significant negation effects for all blocks, *t*s>5.09, *p*s<.001, d_zs>0.73, Δs>0.17flips.

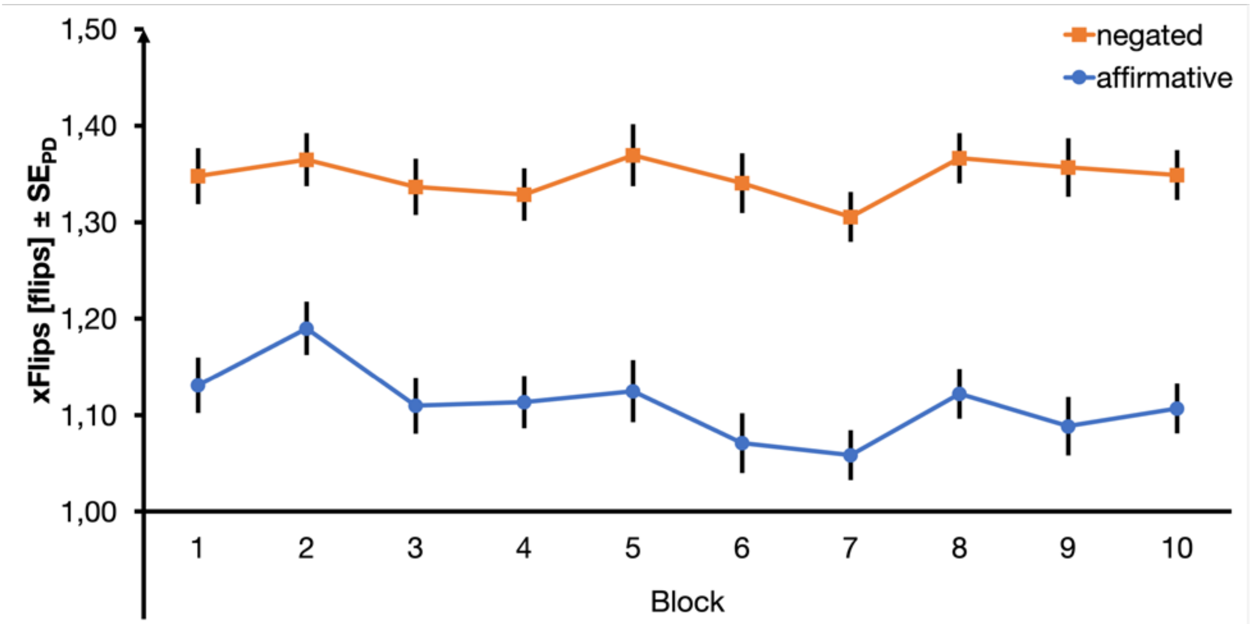

Figure S19. x-Flips (xFlips) results. Mean xFlips are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

ENT (Entropy)

See Figure S20. A significant effect of rule condition, $F(1,47)=190.79$, $p<.001$, $\eta_p^2=.80$, indicated less complex movements for affirmative rules (.0350) than for negated rules (.0422). There was no contribution of block, $F(3,39)=1.99$, $ps>.067$, $\eta_p^2=.32$. Unexpectedly, there was an interaction between both factors, $F(9,39)=2.49$, $p=.024$, $\eta_p^2=.37$, indicating larger differences between affirmative and negated rules for later blocks (Block 1: Δ=.0055; Block 10: Δ=.0093). Planned post-hoc analyses demonstrated significant negation effects for all blocks, $ts>6.39$, $ps<.001$, $d_z s>0.92$, Δs>.0055.

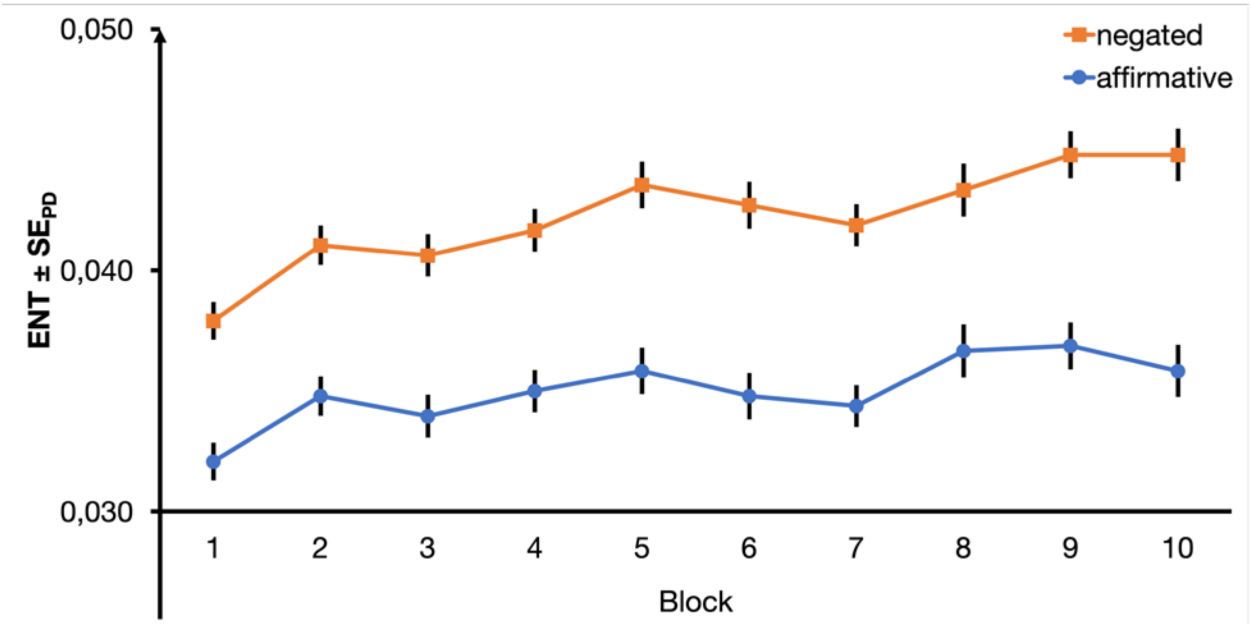

Figure S20. ENT (Entropy) results. Mean ENTs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

MAD (Maximum Absolute Distance)

See Figure S21. A significant effect of rule condition, $F(1,47)=129.29$, $p<.001$, $\eta_p^2=.73$, indicated less spatial deviation for affirmative rules (114px) than for negated rules (155px). Further, a significant contribution of block, $F(9,39)=3.20$, $p=.005$, $\eta_p^2=.43$, showed less direct movements in later blocks (Block 1: 111px; Block 10: 148px), producing a significant linear trend, $F(1,47)=22.04$, $p<.001$, $\eta_p^2=.32$. Unexpectedly, there was an interaction between both factors, $F(9,39)=2.34$, $p=.033$, $\eta_p^2=.35$, indicating larger differences between affirmative and negated rules for later blocks (Block 1: Δ=29px; Block 10: Δ=52px). Planned post-hoc analyses demonstrated significant negation effects for all blocks, *t*s>6.06, *p*s<.001, d_zs>0.48, Δs>29px.

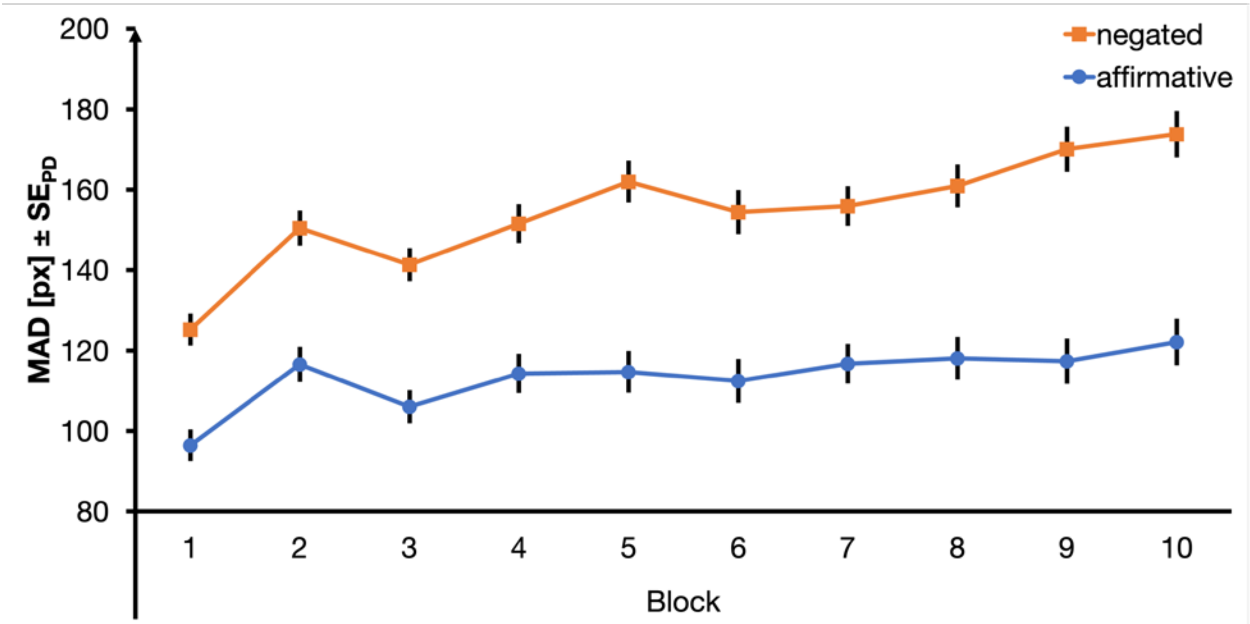

Figure S21. MAD (Maximum Absolute Distance) results. Mean MADs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

Curv (Curvature)

See Figure S22. A significant effect of rule condition, $F(1,47)=76.55$, $p<.001$, $\eta_p^2=.62$, indicated less curved movements for affirmative rules (1.04) than for negated rules (1.06). Further, a significant contribution of block, $F(9,39)=3.12$, $p=.006$, $\eta_p^2=.42$, showed more curved movements in later blocks (Block 1: 1.04; Block 10: 1.06), producing a significant linear trend, $F(1,47)=19.08$, $p<.001$, $\eta_p^2=.29$. Unexpectedly, there was an interaction between both factors, $F(9,39)=2.41$, $p=.028$, $\eta_p^2=.36$, indicating larger differences between affirmative and negated rules for later blocks (Block 1: Δ=0.01; Block 10: Δ=0.03). Planned post-hoc analyses demonstrated significant negation effects for all blocks, ts>4.41, ps<.001, d_zs>0.64, Δs>0.01.

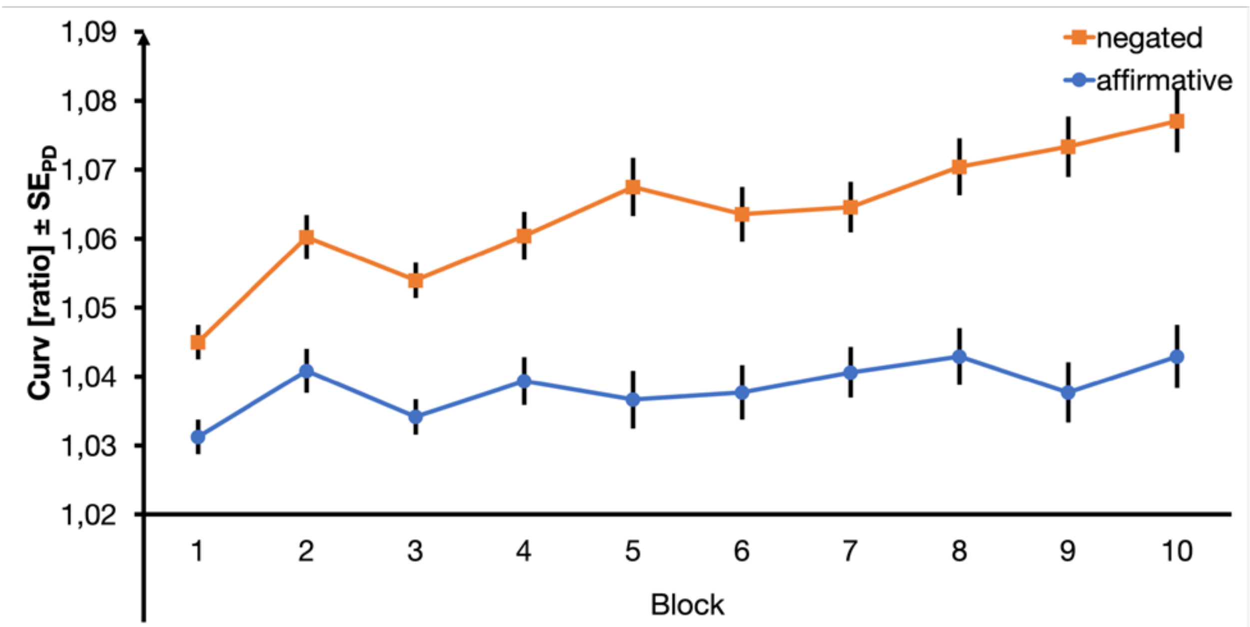

Figure S22. Curv (Curvature) results. Mean Curvs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

TTPV (Time to Peak Velocity)

See Figure S23. A significant effect of rule condition, $F(1,47)=126.27$, $p<.001$, $\eta_p^2=.73$, indicated earlier peak velocity for affirmative rules (54.4%) than for negated rules (59.6%). There was neither a contribution of block nor and interaction between both factors, *F*s<1. Planned post-hoc analyses demonstrated significant negation effects for all blocks, *t*s>6.46, *p*s<.001, d_zs>0.93, Δs>4.6%.

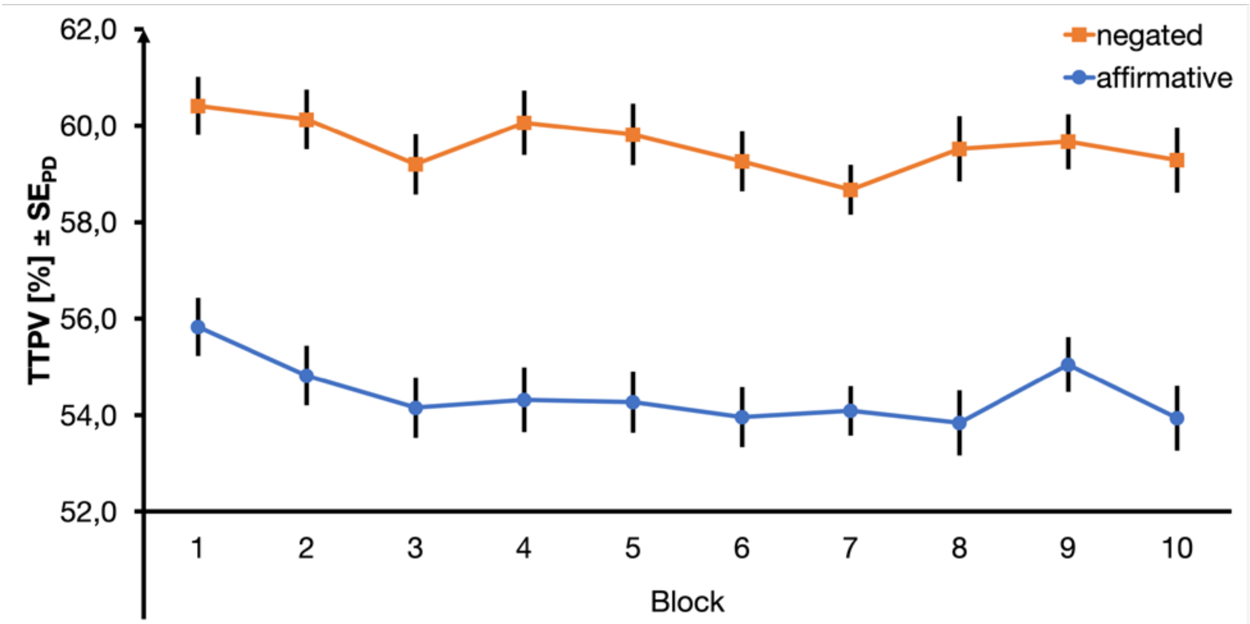

Figure S23. TTPV (Time to Peak Velocity) results. Mean TTPVs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

TTPA (Time to Peak Acceleration)

See Figure S24. A significant effect of rule condition, $F(1,47)=169.35$, $p<.001$, $\eta_p^2=.78$, indicated earlier peak acceleration for affirmative rules (43.2%) than for negated rules (48.5%). There was neither a contribution of block nor and interaction between both factors, Fs<1.62, ps>.144. Planned post-hoc analyses demonstrated significant negation effects for all blocks, ts>5.05, ps<.001, d_zs>0.73, Δs>4.4%.

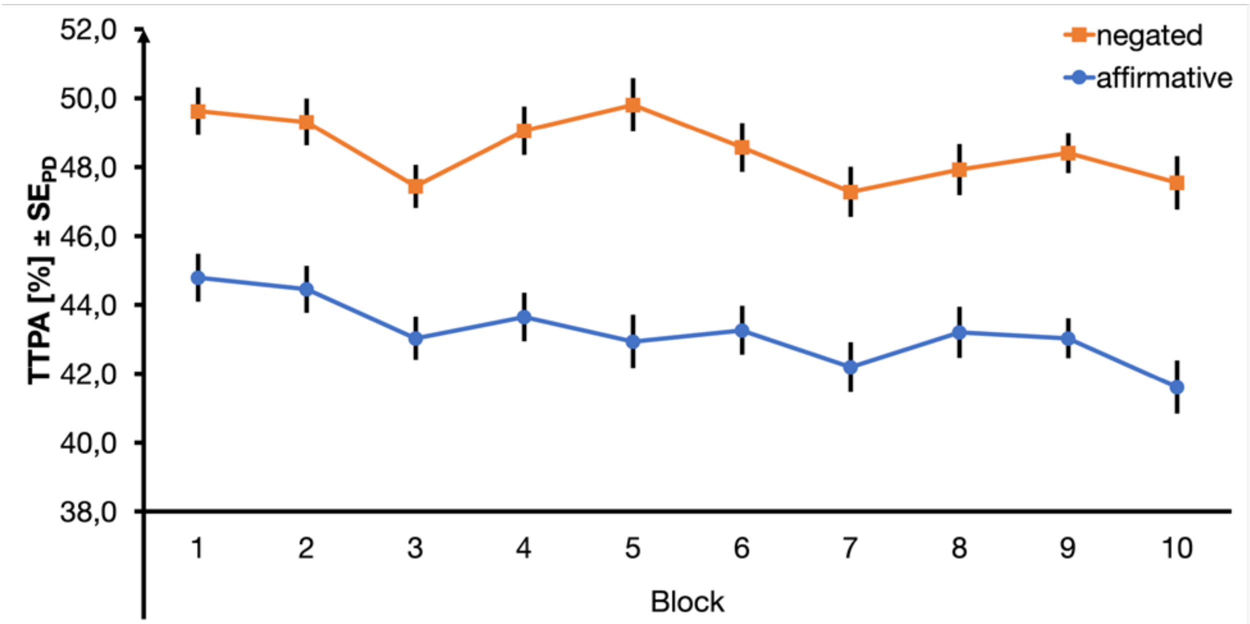

Figure S24. TTPA (Time to Peak Acceleration) results. Mean TTPAs are plotted as a function of block (abscissa) and rule condition (blue circles for the affirmative rule condition, orange squares for the negated rule condition). Error bars represent standard errors of paired differences, computed separately for each block (Pfister & Janczyk, 2013).

Spatio-temporal tradeoff

See Figure S25. We again found a strong negative correlation for both the affirmative, $r(8)=-.834$, $p=.003$, and the negated rules, $r(8)=-.929$, $p<.001$, suggesting a proportional impairment in the spatial domain with every improvement in the temporal domain.

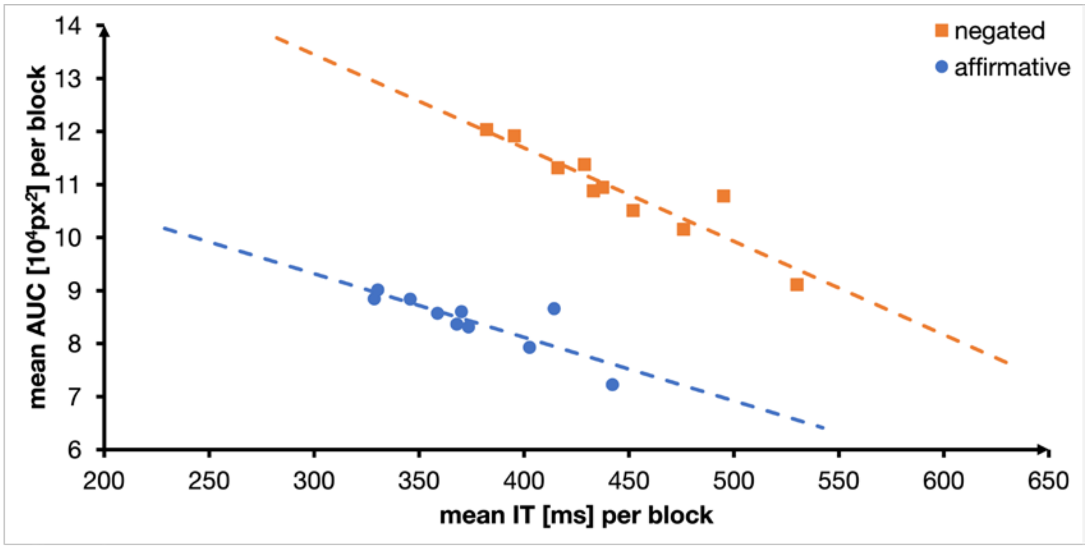

Figure S25. Correlation and regression between IT and AUC data. Mean ITs (abscissa) are plotted against mean AUCs (ordinate), separately for each block (1-10, each data point represents one block: blue dots for affirmative rules, orange squares for negated rules).

Partialling out IT influences in AUC

Again, individual regression slopes on $AUC_{residual}$, separately for each participant and each rule condition over the 10 blocks, did not differ from zero for neither affirmative nor negated rules, *t*s<1.26, *p*s>.213. This suggests that the increase in AUCs can fully be attributed to the spatio-temporal tradeoff.

Partialling out AUC influences in IT

Again, even after partialling out the influence of AUC, there was a significant decrease in ITs for later blocks for both affirmative (at a slope of -7.23ms per block), $t(48)=5.49$, $p<.001$, $d_z=0.56$, and negated rules (-6.94ms per block), $t(47)=6.72$, $p<.001$, $d_z=0.45$. In contrast to the main experiment, regression slopes after partialling out the AUC influences did not differ between affirmative and negated rules, t<1, indicating that performance benefits are comparable for both rule types.

Again, slope ratios suggest that $\frac{-7.23}{-11.46} \approx 63\%$ of improvements with affirmative rules and $\frac{-6.94}{-14.36} \approx 48\%$ of improvements with negated rules can be attributed to practice effects.

Discussion

Overall, the control experiment replicated the results of the main experiment. Even with the methodological changes (a - d, see Introduction), we find that while there are (apparent) performance improvements with increasing practice, large parts of these improvements can be attributed to the spatio-temporal tradeoff. As in the main experiment, we mainly found no interaction between rule condition and block. Interestingly, some interactions turned significant (i.e., for Ent, MAD, Curv) or marginally significant (MinX, AUC, IT). But crucially, these interactions go in the opposite direction as expected, with later blocks, participants seem to show larger negation costs than at the beginning of the experiment (this is true for all spatial measures, whereas IT shows slight temporal improvements, but see spatio-temporal tradeoff).

Hence, the control experiment further speaks against the idea that negations can be improved with training. Even when controlling for the potential confounds (a – d), we show that even after massive, there are still stable response costs for negated compared to affirmative rules.