Lau, H.C., Rogers, R.D., Haggard, P., & Passingham, R.E. (2004). Attention to Intention. *Science, 303*, 1208-1210.

ABSTRACT

Intention is central to the concept of voluntary action. Using functional magnetic resonance imaging, we compared conditions in which participants made self-paced actions and attended either to their intention to move or to the actual movement. When they attended to their intention rather than their movement, there was an enhancement of activity in the pre-supplementary motor area (pre-SMA). We also found activations in the right dorsal prefrontal cortex and left intraparietal cortex. Prefrontal activity, but not parietal activity, was more strongly coupled with activity in the pre-SMA. We conclude that activity in the pre-SMA reflects the representation of intention.

Attention to Intention: Fact or artifact?

PsyCrit, September 1, 2008

In the target paper, Lau, Rogers, Haggard, and Passingham (2004) aimed to identify through fMRI the brain region that codes for the intention to perform a motor act. To that end, they adapted Benjamin Libet's rotating-spot method of timing subjective events (Libet et al., 1983). Subjects watched a red spot revolving around a clock face at a constant speed. They were instructed to wait until the spot completed a full revolution, and then press a button at any time of their own choosing. There were two conditions: In the **Intention** Condition, subjects were instructed to pay attention to their intention to press the button, defined as "...when they first felt the urge to move" (Lau et al., 2004, pp. 1208). After pressing the button, the spot disappeared and reappeared in the center of the clock. Then, subjects were asked to place it where it was when they felt the intention to press the button. In the **Movement** Condition, subjects were instructed to attend to the act of pressing the button, and then report where the spot was when they performed the act.

The key hypothesis was that because of attentional modulation, brain regions coding for intention would be revealed by increased activation in the **Intention** Condition compared to the **Movement** Condition. In terms of behavioral results, subjects reported intention as occurring 228 ms before pressing the button, whereas movement was reported as occurring 29 ms before the recorded button press. In terms of fMRI results, increased activity was found in the pre Supplementary Motor Area (pre-SMA) during intention trials. The authors concluded that activity in the pre-SMA constitutes the neural representation of intention.

Machado and Silva (2007) proposed an alternative account for the results. Lau et al.'s subjects were exposed to two conditions for which they received separate instructions. In one condition they were asked to report when they felt the intention to press the button, and in the other they were asked to report when they actually pressed it. Hence, the experimental procedure may have created a demand characteristic by implicitly asking subjects to behave differently in two different conditions. In other words, by exposing participants to both conditions, a distinction might have been imposed that would not otherwise occur. Therefore, faced with distinct sets of instructions, subjects may simply have been reporting different times for intention and movement because they felt they were expected to do so.

To report different times for intention and movement, subjects might have developed a "script" that allowed them to respond distinctly to the two conditions. It is reasonable to suppose that most adults interpret the term "intention" as referring to something that precedes action. In this way, faced with the **Intention** Condition, subjects would know that (a) they should report something different from what they reported in the movement condition, and (b) they should report something that happened *before* they pressed the button. To produce such a report, subjects could use a variety of means such as giving themselves an order to press the button and interposing between this order and the act a short delay, or even noting the spot position at the moment of the button press and then placing the spot before that position.

Machado and Silva's account (2007) for Lau et al.'s results (2004) is similar to previous attempts (Bridgeman, 1985; Gomes, 2002) to interpret Libet's original data (Libet et al., 1983). To the extent of our knowledge, however, such accounts have never been subjected to empirical test. Our objective with this paper was to provide such a test.

1. Experiment 1

The goal was to design a study without demand characteristics. To that end, we replaced the within-subjects design used in Lau et al.'s (2004) target study by a between-subjects design with two groups. Subjects in the Intention Group performed only the **Intention** Condition, and subjects in the Motor Group performed only the **Movement** Condition. Critically, no subject received the both sets of instructions. If, as Machado and Silva (2007) proposed, subjects in the target study were not attending to intention but putting into play a "script" to conform to the study's demand characteristics, then, eliminating the demand characteristics should eliminate the motive for the "script" and consequently the reason to distinguish between intention and movement; no differences should be observed between the two groups. In contrast, if subjects in the target study were actually monitoring an internal sensation or feeling associated with intention, then the Intention Group should behave differently from the Motor Group.

1.1. Participants

Twenty-two subjects (15 female and 7 male; from 20 to 26 years of age) were randomly assigned to one of two groups, the Intention Group (3 male and 8 female) and the Motor Group (4 male and 7 female).

1.2. Materials and Experimental Procedure

The stimulus, implemented in Java in a laptop computer, consisted of a numberless clock face drawn as a white circle against a black background. In the middle of the circle was a white fixation cross at which subjects were asked to gaze. At the beginning of each trial, a red spot appeared at the 12 o'clock position, and moved in clockwise direction around the perimeter of the circle at a speed of 2520 ms per cycle. Subjects were instructed to wait until the spot completed one full revolution and then to press a mouse button whenever they wanted to. After the mouse button was pressed, the spot continued to move for a random distance between half a turn and a full turn, disappeared and re-appeared in the centre of the clock. Subjects in the Motor Group were instructed to drag the red spot to where it was when they *pressed* the button, whereas subjects in the Intention Group were instructed to drag it to where it was when they *felt the intention* to press the button. Subjects performed 96 trials in total, divided into 4 blocks of 24 trials each. There was a 1-s intertrial interval and a 30-s resting interval between blocks. The subjects performed the experiment alone in a quiet room at the Psychology Department.

1.3. Results

Experiments using Libet's clock paradigm have traditionally used time as their dependent variable (e.g., Libet et al., 1983; Lau et al., 2004a). They have assumed that subjects are performing temporal judgements regarding the occurrence of a certain phenomenon (e.g., intention to move, movement). However, what subjects actually report is not *when* the phenomenon occurred, but *where* the spot was at that time. Time of intention is inferred from subjects' spatial judgements. The indirect measurement of time from spatial position is problematic because the two variables are measured according to different scales. Time is measured on an interval scale with equal intervals and a conventional zero point. It has high and low values such that a time of intention of +2485 ms is considered "higher" than (after) a time of +35 ms. Spatial position on a circle is measured on a circular scale, a special kind of interval scale "where not only is there no true zero, but any designation of high or low values is arbitrary" (Zar, 1999, pp. 592). An angular direction of, say, 355º cannot be said to be "larger" than a direction of 5º. The transformation of spatial judgements into temporal judgments violates this last characteristic of circular scales. In fact, to convert the clock's circular scale of measurement to the interval scale of time is like "cutting" the clock's circumference at an arbitrary point and then flattening it along an axis. Doing so raises issues of ambiguity that would not be present in a purely spatial analysis.

To illustrate, in Libet's task it is impossible to distinguish between a very early and an unusually late intention. If a subject presses the button when the spot is at the 12 o'clock position, until what point in the clock is he considered to be reporting an intention before the button press? Taking into account that the spot starts moving clockwise from the 12 o'clock position, if the subject places the spot at 11 o'clock this means that he is reporting the intention to have occurred about 200 ms before the button press. But suppose the subject places the spot at points "a" or "b" in Figure 1. In the case of point "a", the shortest distance from the point of the button press (12 o'clock) to point "a" is in the direction opposite to that of spot movement. Therefore the subject's intention occurred at point "a" *before* the spot reached the 12 o'clock position. But if we use the same reasoning in the case of point "b", then the shortest distance between the point of the button press and point "b" is in the direction of spot movement. Therefore the subject's intention occurred when the spot passed through point "b" *after* the button press. Thus, the very small spatial distance from "a" to "b" entails a large temporal interval of about 2000 ms (-1000 ms to +1000 ms), which clearly is problematic. If we propose that a report of intention at point "b" still corresponds to an intention prior to the button press, then where do we draw the line? What about a report of intention at point "c"? Would it mean that the subject felt the intention to move more than 3/4 of a rotation before the button press? Or was he reporting a time shortly after the button press, possibly due to some imprecision on his part? To complicate matters, notice that the subject's reports must also be artificially restricted to a period of one turn, because it is impossible to distinguish between multiple turns of the clock.

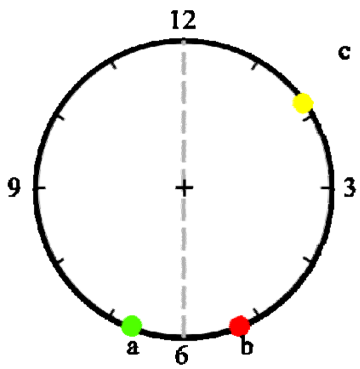

Fig. 1. Example of the ambiguity in the clock paradigm.

Taking into account the great individual variability in the task and the inaccessibility of the subject's putative experience of intention to the experimenter, the implementation of any criterion for disambiguation must be adequately justified. For example, a strict criterion such as dividing the circle in half and not allowing reports earlier than -1260 ms or later than +1260 ms (corresponding to reports before and after the 6 o'clock position, respectively) would not do because it would arbitrarily narrow the response possibilities and simply impose upon the subject's performance the definition of intention tacitly held by the experimenter.

Lacking adequate justification, we simply avoided the foregoing problems by performing a spatial analysis, that is, by examining *where* subjects in each group placed the spot. To contrast conditions we resorted to directional statistics, a domain of statistics concerned, among other aspects, with the analysis of circular data. Essentially, for each trial we measured the angular distance between subjects' reports and the point of the recorded button press. Because these two points are situated on a circle, their location can be expressed in polar coordinates – an angle measured from a given direction (the positive Y axis, to coincide with direction of spot movement). The distance between the two points was expressed by the angle formed between them and the center of the circle. By averaging these angles appropriately (see Smith, 2008, and Zar, 1999, for details), we obtained a vector which indicated where, on average, each subject placed the spot.

Figure 2 summarizes individual and group performance in Experiment 1. The Intention Group is represented in red and the Motor Group in blue. Both individual and group data are represented as vectors. Dotted lines show individual performance and solid lines show group performance. In each case, the vectors' direction points to the average position where a subject or group placed the spot. Vector length indicates how consistent a subject or group's performance was – longer vectors mean greater consistency. Data are plotted as if subjects had pressed the button when the spot was at the 12 o'clock position.

As can be seen from Figure 2, most subjects' reports of spot position cluster around the place where the spot was at the moment of the button press, regardless of the group to which the subjects belonged. There is considerable overlap between groups – although the Intention Group seems to display a slight tendency to report spot positions to the left of the point of the button press.

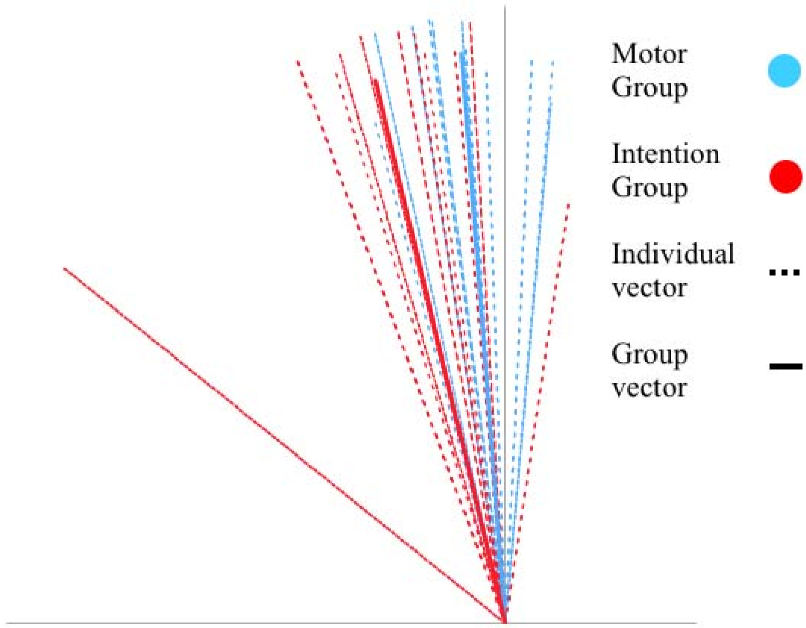

Fig. 2. Group and Individual results for Experiment 1.

To analyze whether subjects in the two groups differed statistically, we compared mean vector angles for the Intention and Motor groups using Watson's test, a non-parametric two sample hypothesis test for angles (see Zar, 1999). No significant difference in mean angle direction was found between the Motor and the Intention Groups ($U^2_{0,05,\ 11,11} = 0,11$, n.s.).

1.4. Discussion

Subjects in the Intention and Motor groups behaved similarly, placing the spot close to where it was when they pressed the button. This result is consistent with Machado and Silva's account (2007): If subjects in Lau et al.'s (2004) experiment were not attending to or reporting an "inner urge" or sensation, but rather responding to demand characteristics by putting into play a "script", then eliminating the demand characteristics should eliminate or at least greatly attenuate the differences between the **Intention** and **Movement** conditions. In the experiment, subjects in each group received instructions only for one condition, and so no demand was placed on them to create a distinction between intention and movement. Hence, as predicted, when the performance of the two groups was compared, no differences were found.

It could be argued that subjects in the Intention Group did not perform the task differently from subjects in the Motor Group because they did not have sufficient training in the task. After all, according to Lau (2007) attending to intention is difficult, and for that reason his subjects received prior practice sessions. However it is unlikely that additional training in the **Intention** Condition would have affected our subjects' reports of intention, as they were already behaving highly reliably: Vector magnitude was higher than 0.85 (max = 1) for all subjects but one.

It is also possible that our subjects failed to discriminate between intention and movement because they were not as aptly trained for it as Lau et al.'s (2004) subjects were. Fine discriminations – e.g. identifying forged works of art or detecting different flavors in wine – often require within-subject training. However, it remains unclear how one would distinguish the case where there are two different occurrences which subjects must be trained to discriminate, from the case in which there are no different phenomena but separate instructions create an artificial distinction.

Experiment 2

In Experiment 2, we aimed to re-create the effect of the demand characteristics embedded in the procedure used by Lau et al. (2004). For this purpose, we adopted the same experimental design used by the authors, but with one important modification. Rather than providing the instructions for both conditions all at once – as Lau et al. did – we separated them. Initially, only one of the conditions was explained to the subjects. After they performed on that condition, they were told there was another condition in the experiment. Our purpose was to compare performance before and after the demand characteristics were instated.

2.1. Participants

Twenty-five subjects (20 female and 5 male; 19 to 26 years of age) were randomly assigned to one of two groups: group "IMMI" (10 female and 3 male) and group "MIIM" (10 female and 2 male).

2.2. Materials and Experimental Procedure

The materials used were the same as in Experiment 1. Experiment 2 was divided into two phases, a training phase and a replication phase. In the training phase, subjects underwent a practice session, as in Lau et al.'s (2004) study. Up to one week afterwards, the same subjects took part in the replication phase, analogous to Lau et al.'s (2004) fMRI session.

Figure 3 details the experimental design. In the training phase, subjects were divided into two groups. Group "IMMI" performed 4 blocks of 20 trials each in the order "Intention-Movement-Movement-Intention", while group "MIIM" performed 4 blocks of 20 trials each in the order "Movement-Intention-Intention-Movement". Each block is referred to by the condition it involved ("I" for Intention, "M" for Motor) and the order in which it was performed (subscript 1 for the first block, 2 for the second, and so on.).

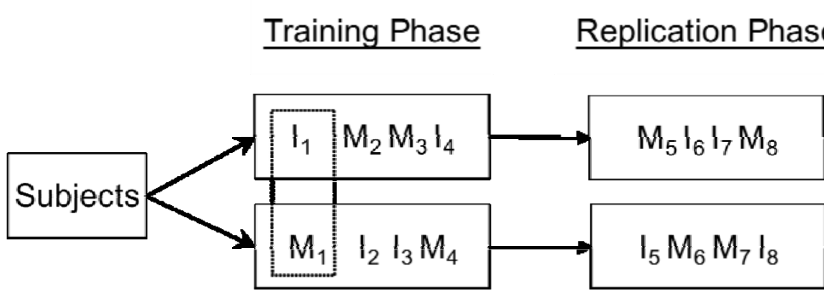

Figure 3. Design of Experiment 2. I=Intention; M=Motor. Subscripts indicate block number. The dotted lines mean that during I_1 and M_1 only a subset of instrutions was given at that time

Experiment 2 used the same set of instructions as Experiment 1. However, in the training phase subjects initially received only the instructions corresponding to the first condition. In group "IMMI" they received instructions only for the **Intention** Condition, whereas in group "MIIM" they received instructions only for the **Motor** Condition. Subjects were told they would be performing the task for 20 trials, after which they should call the experimenter and await further instructions. After the first block of trials, the subjects received the instructions for the remaining 3 blocks of trials.

In the replication phase, we aimed to reproduce the behavioral results obtained by Lau et al. (2004). Up to one week after the training phase, the subjects were exposed to the second part of the experiment, in which they underwent the same procedure but in a different order (MIIM for Group IMMI, and IMMI for Group MIIM) and with 24 trials per block instead of 20. Groups will always be identified by the order in which they underwent training. Thus, Group IMMI refers to the group that performed training in the order IMMI and replication in the order MIIM. During the replication phase, subjects performed the 4 blocks without interruption. At the end of the experiment we debriefed the subject.

2.3. Predictions and Data Analysis

For data analysis, we used the same methods as in Experiment 1. However, given that in Experiment 2 subjects performed under two different conditions it would not make sense to pool the data from all blocks. Therefore, for the training phase, four vectors were obtained for each subject and group, one vector per block. Both between- and within-subjects statistical comparisons were carried out. We were unable to find the ANOVA equivalent in directional statistics and therefore performed only pair-wise comparisons to test the four most relevant hypotheses:

H1: There should be no significant differences between mean vector angle of I_1 and M_1.

The first block of Experiment 2 mirrors the design of Experiment 1. Specifically, groups IMMI and MIIM should behave similarly to the Intention and Motor groups, respectively, from Experiment 1. Because performance of these groups did not differ in Experiment 1, we expect the same result in Experiment 2.

H2: Mean vector angle of I_4 should be significantly different from M_4.

Contrary to I_1, in I_4 subjects were already aware of two distinct conditions, for which they should offer different responses. That is, they should have already developed a “script” to produce distinct reports for the intention and motor conditions. We expect different spot positions in I_4 and M_4.

H3: Mean vector angle of I_1 should be significantly different from I_4.

In I_1 we expect subjects to report spot positions very close to the point where the spot was at the moment of the button press. After performing I_1, subjects are instructed on the **Motor** Condition and, according to the hypothesis, at that moment they realize that there are two conditions in the experiment to which they should respond differently. They then develop the script to report different spot positions for the intention and motor conditions. During I_4 they should use the script and report spot positions markedly different from the positions reported during I_1.

H4: In the replication phase, mean vector angle for intention trials should differ significantly from mean vector angle for motor trials.

By the replication phase subjects have already experienced the two task conditions and should be producing consistently different reports for each. The data should replicate Lau et al.’s (2004) behavioral results.

2.4. Results

2.4.1. Training Phase

Figure 4 represents group performance in the training phase for groups “IMMI” and “MIIM”. As can be seen, subjects in group “IMMI” placed the spot close to where it was when they pressed the button not only during the motor trials (M_2 and M_3) but also during the first intention trials (I_1; see Figure 4a). In contrast, in I_4, they placed the spot before the position they pressed the button. In the case of Group MIIM (Figure 4b), vectors seem to aggregate in two clusters, one close to the Y axis (M_1 and M_4) and another before the Y axis (I_2 and I_3).

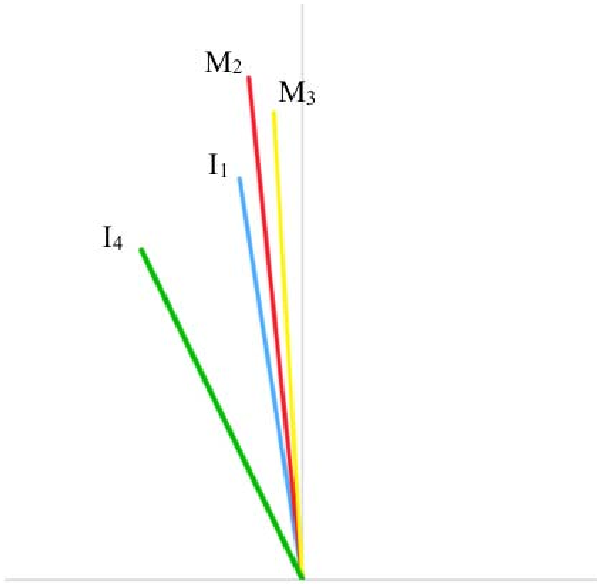

Fig. 4a - Training phase results for group IMMI

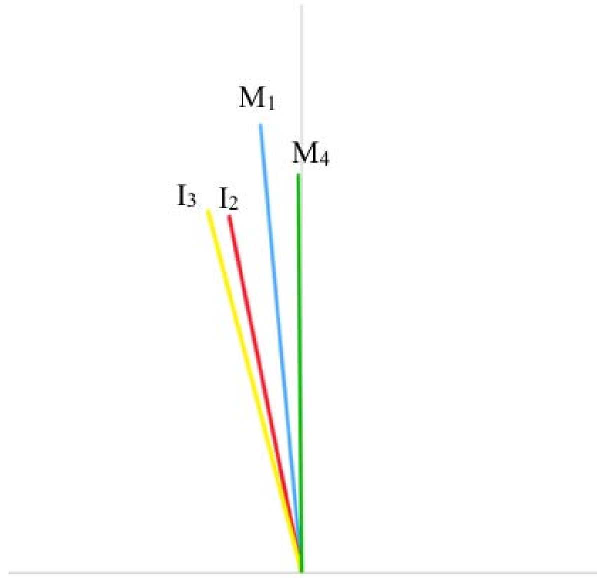

Fig. 4b - Training phase results for group MIIM

To test hypotheses H1 and H2, Watson's test compared the mean angles of the two pairs of vectors. With respect to H1, no significant differences were found in mean angle direction between I_1 (M = 349º) and M_1 (M = 352º), $U^2_{0,05, 13,12}$ = 0,028, p > .05. With respect to H2, significant differences in mean angle direction were found between I_4 (M = 329º) and M_4 (M = 359º), $U^2_{0,05, 13,12}$ = 0,213, $p < .05$. Specifically, angle direction in I_4 was rotated counter clockwise in relation to M_4. This pattern of results is consistent with our predictions.

Within-group comparison of angles was carried out using a non-parametric adaptation of the Hotelling test for paired samples of angles (see Zar, 1999). Contrary to hypothesis H3, no significant differences were found in mean angle direction between I_1 (M = 349º) and I_4 (M = 329º) $R'_{0,05, 13}$ = 0,740, p > .05.

2.4.2. Replication Phase

For each subject, we collapsed all intention and motor trials and then computed two mean-angle vectors, one representing performance in the **Intention** Condition and the other representing performance in the **Motor** Condition. Figure 5 shows the results. The two vectors for each subject are represented by blue (motor) and red (intention) triangles. The filled lines show the averages across subjects. The data show that on motor trials the subjects' reports tended to cluster closer to 0º then on intention trials. There is, however, considerable dispersion in the data. Whereas variability was expected in the **Intention** Condition because, according to our hypothesis, there is no discernible event to which subjects' responses are bound to, we were not expecting substantial variability in the **Motor** Condition because in this case subjects are attending to an objective occurrence. Despite substantial variability the predicted effect was found, as mean angle was significantly different for intention (M = 337º) and motor trials (M = 352º), $R'_{0,005, 25}$ = 1,492, $p < .005$. Specifically, angular direction on intention trials was rotated counter clockwise in relation to motor trials.

To compare our results with Lau et al.'s (2004a) results, we transformed the subjects' spatial judgments of intention and movement into temporal judgments. In our study, subjects reported movement 56 ms before the recorded button press (29 ms in Lau et al.'s study) and intention as occurring 161 ms (228 ms in Lau et al.'s study) before the button press.

2.5. Discussion

As predicted in hypothesis H1, no significant differences were found in mean angle direction between I_1 and M_1. This result independently replicated the results obtained in Experiment 1, which increases confidence in the claim that in the absence of demand characteristics, subjects perform the intention and movement conditions similarly.

Hypothesis H2 was also supported, as mean angle direction of I_4 was significantly different from M_4. The combined results of these two comparisons illustrate the effect of demand characteristics: At the beginning of the experiment, unaware of the existence of another condition, subjects in the intention (I_1) and motor (M_1) conditions behaved similarly, but after hearing the instructions for the remaining trials, subjects became aware that there were two conditions to which they should respond differently, and developed a suitable script. By the final block of training, subjects were using this script to respond differently to the intention (I_4) and motor (M_4) conditions. It seems that subjects only develop a characteristic manner of responding to the **Intention** Condition *after* acknowledging that there is a **Motor** Condition in the experiment, i.e., after the demand characteristics are instated.

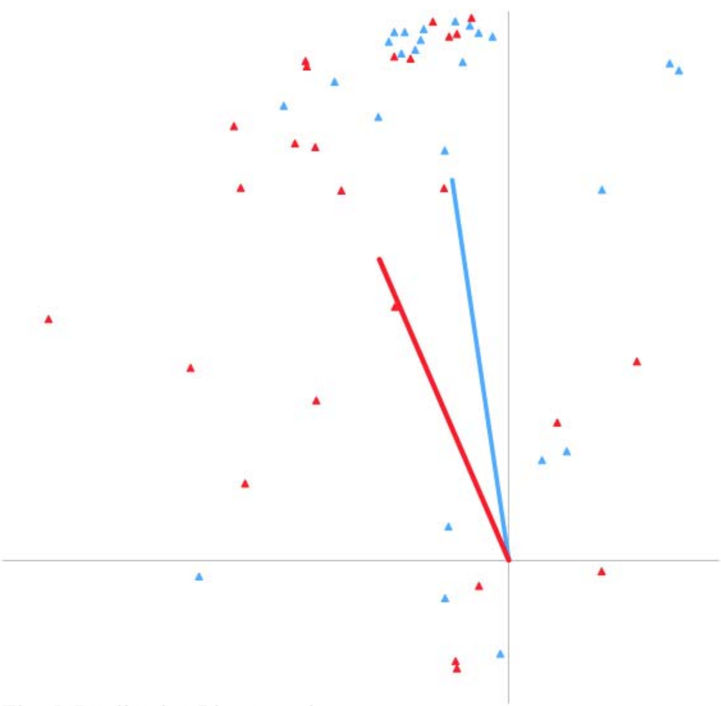

Fig. 5. Replication Phase results

The data did not support hypothesis H3. Although the results were in the predicted direction, with I_4 rotated 20º on the average to the left of I_1, the differences were not statistically significant. The reason may have been the substantial dispersion in the data (see vector magnitudes in Figure 4a).

Finally, data in the replication phase (Figure 5) were consistent with hypothesis H4 as mean angle in the replication phase was found to be significantly different between intention and motor trials. Angular direction in the **Intention** Condition resembled a counter-clockwise rotation of the angular direction in the **Motor** Condition. Importantly, we replicated the order and magnitude of Lau et al.'s (2004a) results on the temporal domain (Motor: 56 vs. 29 ms; Intention: 161 vs. 228 ms).

CONCLUSIONS

Experiment 1 showed that when demand characteristics are absent in an experiment using Libet et al.'s (1983) clock paradigm, there is no reliable difference between the intention and motor conditions. This result suggests that a difference in performance occurs only if subjects are exposed to both conditions, which in turn means that subjects might not be attending to intention and reporting an actual experience of "feeling an urge to move," but rather responding to the study's demand characteristics.

Experiment 1 followed a negative logic: If demand characteristics are responsible for the differences observed between attending to intention and action, then eliminating them should eliminate those differences. Experiment 2 followed a positive logic: If demand characteristics are responsible for the performance differences, then we should observe those differences only after instantiating the demand characteristics. That is, before subjects become aware of the existence of two different conditions, no difference should be found between a group exposed only to motor trials and a group exposed only to intention trials. This was indeed found to be true, replicating and lending further support to the results and conclusions of Experiment 1. But after subjects become aware that there are two conditions, they should be more inclined to report intention earlier than action. The results of Experiment 2 were in that direction, but the differences found were not always statistically significant because of substantial variability.

To summarize, the present study shows that giving both movement and intention instructions to the same subject yields different results than between-subject comparisons (Exp. 1). It also shows that subjects respond differently to the intention instructions before and after becoming aware of the **Motor** Condition (Exp. 2). The study demonstrates on behavioral grounds the important role that demand characteristics play in the paradigm used by Lau et al. (2004). It thus seems that Lau et al.'s (2004) conclusions on the neural representation of intention may be unjustified, that the authors might have imaged an artifact created by the experimental procedure.

More generally, as Machado and Silva (2007) argued, conceptual analysis is an important, but often neglected, tool for psychology in general, but especially for the seductive field of neuroimaging. The mapping of psychological constructs to brain structure requires that the constructs themselves, and the relationships between them, be clear and consistent. William Uttal expressed the same idea when he stated that "However precise may be the measurement (...) used when one is searching for the cerebral site of a cognitive process, the experiment is going to be deeply flawed if the cognitive target is but an artifact, a reification of a hypothetical construct, a name given to a process, or is otherwise imprecisely defined" (Uttal, 2002, pp. 376).

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