Inter-session Reliability and Within-session Stability of a Novel Perception-Action Coupling Task Software

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Abstract:

Traditional measures of alertness and reaction time do not capture the dynamic integration of perception and action, where some form of perceptual judgement (i.e. judgement of an object's spatial parameters in relation to another object) is required to examine this relationship. **PURPOSE:** To assess the reliability, within-subject variability, and systematic bias associated with a novel measure of reaction time, the perception-action coupling task (PACT). **PARTICIPANTS:** 9 males and 7 females (Age (yrs) = 27.8 ± 3.6) participated in four identical testing sessions. **METHODS:** The PACT, performed on a touch-screen tablet, requires participants to make judgements on whether a virtual ball affords "posting" in a virtual aperture, both of varying sizes. There are 8 possible ball to aperture size ratios.~~,~~ ~~and a~~A full cycle of the PACT lasts 5 minutes and consists of 12 randomized presentations of each ratio. For each session, participants completed 9 cycles with a 15-minute break every three cycles. Reaction Time (RT), movement time (MT), and initiation time (IT) were calculated from response parameters. Accuracy of judgements (ACC) was calculated as the percentage of correct responses from each cycle. Systematic bias was determined by repeated-measures ANOVA, reliability was assessed with intra-class correlation coefficients, and within-subject variability was assessed with coefficients of variation. **RESULTS:** Initiation time was found to have the highest learning effect, requiring the elimination of three cycles to eliminate systematic bias (F = 2.417, p = .056). All other variables required one or less cycles (F = .408 - 1.729, p = .167 - .910). All variables showed acceptable reliability (ICC = .775 – 943) and within-subject variability () with only one cycle, after elimination of the first 3 cycles. **CONCLUSIONS:** With a 3 cycle (15-minute) familiarization period, the PACT was found to be stable and reliable in assessing RT, MT, IT and ACC during perceptual judgements.

Introduction:

Perception-action coupling describes the inextricable link between perceiving and acting, whereby action both informs and regulates perception, and what is perceived is simultaneously informed and regulated by the action.[14] Gap closure and the accuracy of action-boundary and action-capability perception, are the behaviors most commonly analyzed to understand how perception-action behavior is regulated.[3, 11, 19, 21, 25, 26, 28, 29] These behaviors are often analyzed in response to changes in the task at hand (e.g., changes in rules, load, control interface sensitivity, stimulus regularity, etc.)[10, 11, 19, 21, 36], changes in the organism (e.g., force production capacity, postural regulation, visual acuity, anxiety, fatigue, etc.)[15, 19, 25, 26, 34], or changes in environmental constraints (e.g., altitude, temperature, etc.). The current study aimed to develop and assess the reliability of a novel measure of perception-action coupling behaviors.

Gap closure refers to goal directed activities which involve intercepting or avoiding objects or events within the environment. Good examples of such goal directed activities relevant to the current study include catching or hitting a ball, jumping a gap, moving a cursor on a computer screen, or steering to avoid a collision.[11, 19, 21, 22] The accuracy of action-boundary and action-capability perception relates to the concept of affordances, whereby the identification of 'opportunities for action' (i.e., affordances) are regulated by an individual's accuracy in relating their own capability for action (maximal jump height, maximum strength, body/object dimension) to an action-boundary (reachable gap to an object, breaking a pencil, fitting through an opening).[13] An action-boundary, as described by Fajen et al.[12], is the critical point at which the limitations of a particular action are met, necessitating a different action in order to maintain a successful motoric response.

Accuracy of perceptual-motor judgements, or the ability of an individual to recognize their action capabilities and action boundaries, has broad implications for successful control and decision-making during movement tasks. Inadequate attunement to these capabilities and boundaries has been shown to result in altered postural control and movement patterns, increased latency in reactionary measures, and decreases in task performance.[9, 15, 21, 23, 24, 27] Summarily, it would seem that the dynamic integration of perception and action is key to a number of variables related to behavioral risk and human performance. It follows, then, that this would be a key feature in an assessment meant to capture changes or disruptions to these domains.

Traditional measures of alertness or reaction time[5, 18, 20] generally require the individual to respond to a given stimulus as quickly as possible; termed, simple reaction time measures.[20] Other measures do require an individual to make a quick decision between responding and not responding based on the type of stimulus, often referred to as “go, no-go” tasks or choice/complex reaction time measures.[5, 18] However, even such choice measures do not require the individual to make a perceptual judgement, based on the spatial or dynamic properties of the presented stimulus. Therefore, they do not encapsulate the types of decisions that must be made when judging affordances for a given movement behavior. That is, the dynamic integration of perception and action is not fully captured by these traditional perceptual-motor judgement instruments.

Research that has incorporated perceptual-motor judgement has shown that successful movement behaviors can be maintained even when reaction time is delayed and movement is initiated at an extended interval from a stimulus signal.[35] A movement solution to a defined task may change in response to changes in organismic or task constraints (i.e. fatigue, sleep disruption, wakefulness), and while initial reaction time increases or remains consistent, other compensatory strategies may be employed to maintain successful overall performance. Therefore, a delayed reaction time, in and of itself, may not be indicative of unsuccessful performance or refer to disturbed motor planning. It is possible that only when a specific series of organismic/task constraints goes beyond a key threshold that successful motor performance can no longer be maintained, irrespective of any accommodations achieved through alterations in motor coordination to solve a specific movement task.

In summary, more sensitive, ecologically valid and robust measures are required to enable the identification of the thresholds that induce perceptual deficits. Based on this need, a novel perception-action coupling task software (PACT) was developed following a task first described by Smith and Pepping[35]. In their study, a computer-based task was described in which participants were asked to make judgements on whether balls of varying sizes afforded posting through apertures of varying sizes.[35] Several alterations were made to this task to make it more user friendly, with the most prominent change being development of the software program as a tablet-based application with a touchpad user interface.

Before it can be established whether this software can provide an ecologically valid measure of an individual's ability to accurately identify affordances for action, it must be shown to be a reliable and stable measure. Therefore, the purpose of this study was threefold: to (1) establish the extent of any systematic bias between testing, (2) examine the test-retest reliability, and (3) determine the within subject variability associated with the PACT outcome data. Several previous studies on the reliability of behavioral measures have demonstrated significant between-session, systematic bias[8, 32, 38], thus it was included in this study, despite being absent from most research investigating the reliability of reaction time measures.

Methods:

Study Design and Participants:

An observational, test-retest design was employed for the current study. Sixteen participants (Males / Females = 9 / 7, Age (yrs) = 27.8 ± 3.6) reported to the lab for four testing sessions. Subjects were asked to refrain from consuming any caffeine in the four hours prior to testing, and to arrive in a well-fed, well-rested and alert state. To be included in the study participants had to meet the criteria of: having corrected 20/20 vision, being free from any visual impairments, and having no need to take medications that would have impaired cognitive processes, alertness or vision. Before administration of the PACT, participants were familiarized with study protocols and reviewed and signed an Informed Consent, previously approved by the University of Pittsburgh Institutional Review Board.

Procedures:

During each of the four testing sessions, participants completed nine identical cycles of the PACT in a quiet environment, with minimal distractions. The PACT requires the participant to make determinations as to whether a series of virtual balls (diameter ranging from 10mm-60mm) presented on an iPad (Apple Inc., Cupertino, CA) afford posting (can fit) through a series of virtual apertures (diameter ranging from 18mm-44mm). Eight ratios of aperture size to ball size were presented, ranging from 0.2 to 1.8, depicted in Figure 1. Ball and aperture size ratios were presented in a randomized order, and each ratio was presented 16 times across each cycle. To perform the PACT, participants started with their index or middle finger of their dominant hand on the starting button (depicted in Fig. 1). At a randomized interval, between .34 and .37 seconds, the ball and aperture appeared on the screen. If the participant determined that the ball could be posted through the aperture, they moved their finger from the starting position to a virtual joystick (depicted in Fig. 1), swiping upwards to direct the ball towards the hole. If they determined that the ball could not be posted, the participant moved their finger to the joystick, swiping downwards to direct the ball away from the aperture. As soon as the action was completed, the participants moved their finger back to the start button. Participants were instructed to respond as quickly and accurately as possible and were not provided feedback about their performance throughout testing.

Each cycle of the PACT lasted approximately 5 minutes, depending on how quickly participants moved their finger back to the start button after each movement. Participants were given a fifteen-minute break after completing each set of three consecutive cycles. During breaks, participants were allowed to move around, rest and relax. Testing sessions were separated by at least 6 days, to allow for washout, and the mean number of days in between sessions was 9.67 ± 3.4. Finally, across sessions participants were scheduled for the same general time of day (morning, afternoon, evening).

Data Reduction:

To assess the accuracy of action boundary judgements (ACC), the ratio of correct to incorrect responses was calculated for each cycle and expressed as a percentage based on the following formula:

$$Correct\ response\ ratio = \frac{Number\ of\ correct\ responses}{Number\ of\ pairings} \times 100$$

A correct response was considered one where either: a) the ball afforded posting and the subject swiped forward on the joystick, b) ball did not afford posting and the subject swiped backwards on the joystick. The reactive component of the PACT was analyzed for only correct responses by dividing the total time between the presentation of the stimulus (the ball-aperture pairing) and the response into different phases. Reaction Time (RT) was calculated as the time interval between the presentation of the stimulus and the participant lifting their finger off the start button. Movement time (MT) was calculated as the time interval between the participant lifting their finger and initiating a movement with the joystick. Finally, initiation time (IT) was calculated as the time interval between the participant initiating a movement with the joystick and completing the movement.

Statistical Analyses:

All statistics were performed using IBM SPSS 23.0 (IBM, Armonk, NY). An iterative approach was taken to the data analyses in an attempt to not only identify the inherent stability of the PACT data, but the relevant testing parameters (i.e. familiarization period, number of testing cycles) necessary to achieve stable measures with the PACT. To assess the presence of systematic bias within each variable (ACC, RT, MT, IT), 4 x 9 repeated measures analysis of variance (ANOVA) were first calculated, with session (4 levels) and cycle (9 levels) as the two within-subject factors. Further, time-series plots were formulated for visual assessment. Sphericity was assessed with Mauchly’s test of sphericity, and a Greenhouse-Geiser correction (GG) was applied to p-values as appropriate. The interaction factor (session x cycle) was assessed for each ANOVA, and given the presence of a significant interaction, cycles were eliminated until the systematic bias was eliminated (i.e. 4 x 8, 4 x 7, etc…) Next, the main effects of session and cycle were examined and marginal comparisons were performed with paired t-tests, using Bonferroni-corrected p-values, when main effects were found to be significant.

After cycles had been removed to eliminate systematic bias, intra-class correlation coefficients {ICC (3,1)} were calculated in an iterative manner, averaging variables across all remaining cycles first and systematically eliminating cycles and re-calculating coefficients. This was done on a case by case basis, dependent on the results of the ANOVA for each variable (i.e. if the first 3 cycles were eliminated, then the first cycle included was cycle 4). Finally, the mean coefficients of variation were calculated for each variable using this same process, to assess within-subject variability across testing sessions. Coefficients were calculated using the typical error of the measure (CV_{TE}), as described by Hopkins[17]. In the case of MT, which showed significant departures from normality across cycle averages, log transformations were applied before calculating CV_{TE}, also as described by Hopkins[17].

Results:

Time-series plots depicting the variability of all variables across cycles and sessions are located in Figure 2. Results of inferential statistics are summarized below.

Reaction Time:

The results of the repeated-measures, 4 x 9 ANOVA, including all cycles, showed no presence of systematic bias for RT. Examination of the interaction term showed no significant interaction of session x cycle (F = .408, p (GG) = .910). A significant main effect of cycle (F = 2.802, p = .007, partial η^2 = .157) was observed, however, marginal comparisons did not show any significant differences in RT averaged across cycles (Mean difference (sec) = .001 - .008, p = .225 - 1.00). All cycles were included for calculation of ICCs and CV_{TE}.

Movement Time:

The results of the repeated-measures, 4 x 9 ANOVA for MT mirrored those for RT, with (F = 1.729, p (GG) = .167) and non-significant main effects for both session and cycle (F = .391 - 2.329, p (GG) = .128 - .672). All cycles were included for calculation of ICCs and CV_{TE}.

Initiation Time:

Initiation time was found to have the most variability, requiring the elimination of the first three cycles from testing sessions before the presence of systematic bias was removed. The results of the repeated-measures, 4 x 6 ANOVA showed the interaction term to be non-significant (F = 2.417, p (GG) = .056). Examination of the main effects showed a significant main effect of session (F = 4.491, p = .008, partial η^2 = .230), however examination of the marginal comparisons revealed no significant differences in IT averaged across sessions (Mean difference (sec) = .001 - .043, p = .063 - 1.00). Results of the ICCs and CV_{TE} for all variables can be found in Table 1. For IT, cycles 4-9 were included in the analysis.

Accuracy:

Judgement accuracy required one cycle be eliminated from each session to remove the presence of systematic bias. The results of the repeated-measures, 4 x 8 ANOVA revealed a non-significant interaction term (F = 1.449, p (GG) = .226). The main effect of session was found to be significant (F = 3.246, p = .031), however marginal comparisons showed no significant differences in ACC averaged across session (Mean difference (%) = .055 - 2.367, p = .168 - 1.00). Cycles 2-9 were included for calculation of ICCs and CV_{TE}.

Follow-up Analysis:

Because IT was found to require the removal of 3 cycles to eliminate systematic bias, a follow-up analysis was conducted where ICCs and CV_{TE} were re-calculated for all other variables starting with the 4^{th} cycle. The results of these tests can be found in Table 2.

Discussion:

The current study was undertaken to investigate the reliability and stability of a novel measure of reaction time and accuracy; the PACT. The first purpose was to investigate the presence of systematic bias, over repeated sessions and testing cycles of the PACT. Results of repeated measures ANOVAs demonstrated that most variables (MT, RT, and ACC) only required the removal of one or zero cycles to eliminate significant between-session, within-session, or interaction effects. However, IT required the removal of the first three cycles before the session by cycle interaction term became non-significant ($p > .05$). These results indicate the need for three cycles (approximately 15 minutes) to obtain a baseline familiarity with the PACT and stable measures for all variables assessed by the PACT. Following this familiarization session, no significant systematic bias was detected for any of the variables.

Previous literature on reaction time measures of a similar nature have generally failed to report analyses for systematic bias, making comparisons difficult. One study by Ayala et al.[2] found no systematic bias in hamstrings reaction time, based on latency between a stimulus and muscle activation. However, the authors only report the results of the trial by session interaction effect, with no information on between- or within-session effects. This is especially troublesome given that several studies assessing the reliability of motor pattern or performance metrics (i.e kinematics, single-leg squat performance) have reported significant systematic bias due to a between-sessions effect.[8, 32, 38] These studies have all shown significant differences between the first session and all following sessions, indicating the need for a full familiarization session.

The second aim of the current study was to investigate the test-retest reliability of the PACT. In this effort, cycles were eliminated for each variable to remove the presence of systematic bias and ICCs were calculated in an iterative manner to provide estimates of improvement in reliability with the addition of multiple testing cycles. The interpretation of reliability statistics is variable, with recommendations for acceptable reliability ranging from an ICC of .60 to .90.[1, 16, 30, 31] However, Heaton et al.[16] reviewed studies assessing the reliability of neuropsychological measures and reported a range of .70 to .90 as "generally good". Based on this criteria, IT, MT, and RT were all found to have acceptable reliability with only one cycle of testing, with ACC requiring 4 cycles (Table 1). In examining the trend in ACC (Fig 2), this effect is evident, with the first three cycles of the first session showing marked improvement, and then leveling off for the remaining cycles and sessions. Further, when the first three cycles were removed due to the systematic bias present in IT (Table 2), only one cycle was required to reach adequate reliability for all variables. Overall, the PACT demonstrated superior reliability compared to similar measures, with previously reported ICCs on choice reaction time tasks ranging from .26 - .69, and the majority in the range of .46 - .52.[2, 4, 6, 7, 33, 37]

The final aim was to investigate the within-subject variability inherent in the PACT, utilizing the same iterative process as for the test-retest reliability. Like reliability, the interpretation of CV_{TE} is variable and dependent on the type of measure being assessed, as well as the expected magnitude of change a researcher or clinician wishes to detect. Also, like systematic bias, a lack of studies reporting within-subject variability for similar measures makes it hard to, at the very least, formulate an expected value for the CV_{TE}. Two studies have included the standard difference of the error for choice reaction time tasks, reporting values of 12.77% and 19.38%. While there are slight differences in the calculation of these metrics (CV and standard error of the difference), these studies provide the best comparison to the current one.

Initiation time and MT demonstrated the greatest effect of additive testing cycles on the CV_{TE}, with RT and ACC showing no significant change in the CV_{TE} beyond the first cycle (Table 1). Initiation time required two cycles to achieve a stable CV_{TE} (4.07%), where the addition of cycles produced only a minimal change in the coefficient, and MT required four cycles (15.30%). However, related to previously reported values discussed above, IT showed a consistent CV_{TE} with only one cycle (11.88%) and MT with three cycles (17.27%). Further, when interpreting the coefficients for MT after removal of the first three cycles (Table 2), the CV_{TE} was stable with two cycles (16.23%) and consistent with previous studies with only one (19.28%). Overall, the results demonstrate that, following a three-cycle familiarization period, a single cycle of testing produces within-subject variability of the PACT, across all variables, consistent with that observed in the previous literature on complex reaction times. However, while data derived from two cycles improves the stability of the CV_{TE} values, the addition of further cycles yield a minimal reduction in the within-subject variability.

In summary, the results of the current study demonstrate that, with a three-cycle familiarization period, the PACT demonstrates no systematic bias, good reliability, and within-subject variability that is consistent with expected values, requiring only one five-minute cycle of testing. However, in cases where investigators or clinicians require a highly reliable measure or are interested in variables that may elicit smaller changes in PACT performance, two cycles of testing may be required (10 minutes). Finally, these are general recommendations and we urge individuals to consider the results for themselves and make a decision on the necessary familiarization and testing periods based on their specific needs.

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Figure 1. Depiction of PACT interface and example ball to aperture ratios

*** INSERT FIGURE 1 HERE ***

- Ball = circle at bottom of screen, aperture = circle at top of screen, start button = button on the bottom right ("tap and hold"), joystick = button to the left of the start button

Figure 2. Means and errors for IT, MT, RT, and ACC across cycles and sessions

*** INSERT FIGURE 2 HERE ***

Table 1. Intra-class correlation coefficients and coefficients of variation by cycle

	ICC	95% CI	CV_{TE}	95% CI
Reaction Time:				
9 Cycles	.884	.750 - .955	9.24%	7.51 - 12.07%
8 Cycles	.882	.745 - .954	9.68%	7.86 - 12.64%
7 Cycles	.883	.748 - .955	9.72%	7.90 - 12.70%
6 Cycles	.874	.728 - .951	10.13%	8.23 - 13.24%
5 Cycles	.872	.725 - .950	9.90%	8.04 - 12.93%
4 Cycles	.866	.711 - .948	10.11%	8.21 - 13.21%
3 Cycles	.853	.683 - .943	11.35%	9.22 - 14.83%
2 Cycles	.870	.721 - .950	9.22%	7.49 - 12.05%
1 Cycle	.865	.710 - .947	10.35%	8.41 - 13.53%
Movement Time:				
9 Cycles	.980	.956 - .992	12.33%	9.90 - 16.40%
8 Cycles	.979	.955 - .992	12.94%	10.39 - 17.24%
7 Cycles	.977	.950 - .991	13.55%	10.87 - 18.06%
6 Cycles	.975	.947 - .990	13.90%	11.15 - 18.53%
5 Cycles	.971	.938 - .989	14.97%	12.00 - 20.44%
4 Cycles	.964	.923 - .986	15.30%	12.26 - 20.44%
3 Cycles	.956	.906 - .983	17.27%	13.82 - 23.14%
2 Cycles	.943	.879 - .978	20.26%	16.17 - 27.25%
1 Cycle	.877	.739 - .952	25.33%	20.12 - 34.30%
Initiation Time:				
6 Cycles	.547	.060 - .821	43.28%	35.16 - 56.54%
5 Cycles	.642	.244 - .860	50.72%	41.19 - 66.25%
4 Cycles	.972	.931 - .990	7.20%	5.85 - 9.40%
3 Cycles	.974	.946 - .990	5.95%	4.83 - 7.77%
2 Cycles	.992	.983 - .997	4.07%	3.31 - 5.32%
1 Cycle	.906	.785 - .964	11.88%	9.65 - 15.52%
Accuracy:				
8 Cycles	.787	.519 - .918	2.42%	1.96 - 3.16%
7 Cycles	.795	.514 - .923	2.39%	1.94 - 3.13%
6 Cycles	.786	.504 - .918	2.00%	1.62 - 2.61%
5 Cycles	.767	.474 - .911	2.13%	1.73 - 2.79%
4 Cycles	.700	.359 - .882	2.87%	2.33 - 3.75%
3 Cycles	.602	.204 - .837	3.53%	2.86 - 4.61%
2 Cycles	.545	.127 - .809	4.13%	3.36 - 5.40%
1 Cycle	.362	-.265 - .741	4.58%	3.72 - 5.98%

- ICC = Intra-class correlation coefficient, 95% CI = 95% confidence interval
- Initiation time: begins with 4th cycle, movement time and reaction time: begins with 1st cycle, accuracy: begins with 2nd cycle
- Movement time: CV_{TE} result of log transformed values

Table 2: Intra-class correlation coefficients and coefficients of variation for movement time, reaction time, and accuracy with first three trials removed

	ICC	95% CI	CV_{TE}	95% CI
Reaction Time:				
6 Cycles	.873	.726 - .951	9.11%	7.40 - 11.90%
5 Cycles	.799	.537 - .923	9.07%	7.37 - 11.85%
4 Cycles	.869	.718 - .949	9.30%	7.56 - 12.15%
3 Cycles	.849	.674 - .941	11.10%	9.01 - 14.50%
2 Cycles	.849	.675 - .941	12.04%	9.78 - 15.72%
1 Cycle	.830	.634 - .934	12.72%	10.33 - 16.61%
Movement Time:				
6 Cycles	.979	.955 - .992	14.06%	11.27 - 18.75%
5 Cycles	.972	.935 - .990	13.55%	10.87 - 18.06%
4 Cycles	.978	.953 - .991	14.64%	11.74 - 19.54%
3 Cycles	.979	.955 - .992	15.34%	12.29 - 20.49%
2 Cycles	.972	.940 - .989	16.23%	12.99 - 21.71%
1 Cycle	.943	.878 - .978	19.28%	15.82 - 26.64%
Accuracy:				
6 Cycles	.766	.511 - .908	2.62%	2.13 - 3.42%
5 Cycles	.749	.473 - .901	2.87%	2.33 - 3.75%
4 Cycles	.815	.612 - .927	2.02%	1.64 - 2.64%
3 Cycles	.809	.598 - .925	2.19%	1.78 - 2.86%
2 Cycles	.820	.621 - .929	2.05%	1.66 - 2.67%
1 Cycle	.707	.391 - .884	3.28%	2.66 - 4.28%

- ICC = Intra-class correlation coefficient, 95% CI = 95% confidence interval
- All variables begin with 4^{th} cycle
- Movement time: CV_{TE} result of log transformed values