

RESPIRATORY PHASE AND PRECISION MOTOR CONTROL: DISTINGUISHING ACTION SELECTION FROM EXECUTION ERROR

Susan Azizi and Niloofar Ahmadi*

Department of Sport Science, Faculty of Humanities, Tarbiat Modares University, Tehran, Iran

Received: 01/8/2024 Revised: 26/09/2024 Accepted: 29/11/2024 Published: 20/12/2024

Correspondence: niloofar.ahmadi@yahoo.com

ABSTRACT

Respiratory timing can accompany a manual action without determining its execution accuracy. Interpretation requires distinctions among action selection, force steadiness, target error and endurance. In this article eight human performance experiments were appraised by task, respiratory manipulation, endpoint, source accessibility and inferential limitation. Neural and physiological studies supplied mechanistic context. Conditional-expectation identities and an additive periodic-error model were used to examine phase selection and interval averaging. Coordination was associated with improved tracking precision and inspiratory handgrip endurance in specific tasks, whereas other experiments identified amplitude-related force fluctuations or frequency-related changes in response speed. These findings address different outcomes and do not establish a universal phase advantage. Evidence strength is restricted by small or selective samples, abstract-only access for several reports and inconsistent statistical reporting in one experiment. The calculation shows that averaging over complete cycles removes a periodic contribution from signed bias while preserving its contribution to mean-square error. Partial-cycle results depend on duration, onset phase, perturbation lag and constant bias. The contribution is an outcome-specific interpretation of respiratory exposure during movement execution, rather than a new mathematical theorem or a validated breathing intervention. Prespecified contrasts involving support, sensory timing, ventilation and analysis duration can distinguish competing explanations of respiratory associations in precision kinesiology.

Keywords: interoception; sensorimotor integration; isometric contraction; visuomotor tracking; thoraco-abdominal motion; circular statistics; neuromechanics

INTRODUCTION

Maintaining a small pinch force, steering a hand along a visual trajectory and initiating a brief response are all motor tasks, yet they place different demands on the performer. A force-holding task penalizes fluctuations throughout an interval; a response task can principally reward rapid initiation. Breathing accompanies both. In a laboratory study of index-finger abduction, increasing respiratory amplitude altered force variability and its interaction with visual feedback (Baweja et al., 2011). In a separate investigation, self-initiated button presses occurred preferentially during expiration, whereas externally triggered actions did not show the same coupling (Park et al., 2020). These observations concern different aspects of movement and should not be treated as equivalent demonstrations of enhanced motor performance.

The distinction becomes especially important when an intuitive coaching statement, such as performing a precise action while exhaling, is given a neuroscientific explanation. An action can occur more often in a particular phase because that phase is selected, because the task reorganizes breathing, or because the available time differs between phases. None of these possibilities independently determines endpoint error. Moreover, visually guided forearm tracking has shown changes in the pattern of motor-respiratory coordination under different instructions and signal-response relations

(Krupnik et al., 2015). The relationship is consequently sensitive to what the person is trying to accomplish, not simply to the presence of inspiration or expiration.

Precision also requires careful definition. Force steadiness describes temporal fluctuations during an intended steady contraction; it is related to the discharge organization of motor units, but it is not interchangeable with movement speed or the mean level of force (Enoka and Farina, 2021). Accuracy concerns agreement with a target, while precision concerns consistency. A consistently excessive force can have low variability and poor accuracy. Conversely, positive and negative deviations can cancel in the average while remaining functionally disruptive. Any argument about breathing and accurate movement must therefore specify whether its endpoint is latency, bias, fluctuation magnitude, spatial deviation or successful task completion.

Respiration makes this problem interdisciplinary in a precise sense. It is a rhythmic motor behavior maintained by distributed neural control, a source of bodily sensory information and a mechanical event that displaces the thorax and abdomen. Its rhythm and pattern are adaptable rather than fixed outputs of an isolated brainstem oscillator (Ashhad et al., 2022). Kinesiology supplies the movement endpoint; neuroscience supplies candidate timing and sensory mechanisms; respiratory physiology supplies ventilation and gas-exchange constraints; and biomechanics supplies the transmission of bodily motion to a task effector. Their correspondence is strongest when the same task is described in all four domains.

Existing reviews already distinguish respiratory protocols and their neural, biochemical and behavioural effects. Heck and colleagues discuss respiration-linked oscillations in cognition and emotion (Heck et al., 2022); Goheen and colleagues examine respiratory modulation of neural and mental activity, including concurrent physiological changes (Goheen et al., 2023). Accordingly, the presence of a breathing–brain relationship is not the novelty claimed here. The present contribution concerns how action scheduling and the respiratory exposure of an execution interval jointly affect interpretation of a specified motor-error outcome. It applies established mathematical relationships to compare onset-phase distributions, conditional error and duration-dependent averaging.

The guiding question is whether a respiratory phase associated with action initiation also predicts lower error during execution. The review addresses laboratory precision movements and uses endurance evidence as an explicit endpoint contrast. It does not attempt to summarize all locomotor–respiratory coordination, respiratory rehabilitation or breathing interventions. The analytical objective is to identify observable results that would support or contradict an interval-averaging explanation, without assuming a universal instruction for athletes.

RESULTS OF THE CRITICAL ANALYSIS

PERFORMANCE FINDINGS DEPEND ON MANIPULATION AND ENDPOINT

The most direct evidence concerning sustained precision comes from force holding and tracking. In 20 young adults, Baweja and colleagues varied respiratory amplitude and visual feedback during index-finger abduction. High-amplitude breathing increased force variability by approximately 63% relative to normal breathing; visual feedback further modified the effect at moderate effort (Baweja et al., 2011). The simultaneous respiratory, force and electromyographic measurements strengthen the task-level association. Nevertheless, changing breath amplitude does not isolate onset phase, and amplified low-frequency force power does not identify one exclusive neural or mechanical pathway.

Krupnik and colleagues examined 35 volunteers during visually guided forearm tracking. Motor–respiratory coordination improved tracking precision in every condition except relaxed instruction, principally through reduced amplitude error. Increased complexity or attention changed the preferred phase-coupling pattern (Krupnik et al., 2015). This positive result is material to the review: coordination can support control rather than merely disturb it. Its abstract-level evidence does not permit detailed reassessment of the within-trial comparisons or uncertainty estimates, and preferred coordination during repeated tracking does not establish the best phase for a discrete movement.

Response tasks address a different question. Li and colleagues found a breathing-condition-by-cue-phase interaction in 13 healthy participants, with slower responses to expiratory cues during voluntary breathing at 0.6 Hz (Li et al., 2012). Park and colleagues instead observed expiratory clustering of self-initiated button presses, absent during externally triggered actions, together with respiratory modulation of readiness-potential amplitude (Park et al., 2020). The externally triggered comparison strengthens the specificity of action selection, but the experiment did not establish improved target accuracy. Cue phase, movement phase and choice of onset are distinct temporal variables.

Buchanan and Janelle examined 47 participants producing a memory-guided pinch pulse at 10% maximal voluntary contraction (MVC). Fast paced breathing shortened reaction and movement times; the abstract describes maintained accuracy and variability (Buchanan and Janelle, 2021). This is compatible with a speed benefit in that task, rather than evidence that faster breathing reduces error. Without an equivalence margin and interval estimate, maintained accuracy should not be read as demonstrated equality across breathing conditions.

Their later experiment assessed pinch responses after emotionally valenced images (Buchanan and Janelle, 2022). Slow

breathing delayed responses, and fast breathing increased error in a neutral-image comparison. The breathing-by-valence interaction was not statistically significant, so that subgroup result does not establish emotional moderation. Reporting discrepancies also restrict quantitative interpretation: 35 participants are described, whereas several tests use denominator degrees of freedom incompatible with a conventional complete-case three-level repeated-measures analysis of that sample; the force-error figure caption uses time units. These discrepancies concern the cited report, not observations generated here. Its broad endpoint distinction is retained, while its subgroup and effect-size claims receive limited weight.

Li and colleagues provide a useful endurance comparison: 11 participants completed rhythmic handgrip trials to failure in randomized conditions, with longer normalized exhaustion time during inspiratory coordination than expiratory coordination or unrestricted breathing (Li et al., 2024). This supports a task-specific performance benefit. It neither demonstrates lower target error nor establishes that neural energy expenditure caused the benefit.

RESPIRATION-LINKED NEURAL ACTIVITY SUPPLIES POSSIBILITIES, NOT A MOTOR PRESCRIPTION

A motor-specific neural experiment provides a closer bridge than cognitive tasks alone. Kluger and Gross recorded magnetoencephalography, muscle activity and respiration during steady contraction. Beta-band corticomuscular coherence was reduced during voluntary deep compared with normal breathing and varied cyclically with respiratory phase in both conditions (Kluger and Gross, 2020). This demonstrates modulation of cortico-peripheral synchrony under a motor demand. Coherence is still not force error, and the deep-breathing contrast changes voluntary control as well as depth. The result therefore supports a neural route for investigation without locating a phase that minimizes target deviation.

Park and colleagues also observed breathing coupling with voluntary initiation of motor and visual imagery, including tasks without overt limb movement (Park et al., 2022). This supports a preparatory association beyond mechanical transmission during movement, but does not identify a cause of execution error. Imagery onset and motor accuracy remain different outcomes.

The neural evidence establishes that breathing can organize processes beyond gas exchange. Zelano and colleagues recorded respiration-related oscillatory activity in human limbic structures and examined respiratory-route and phase relationships with cognitive performance (Zelano et al., 2016). The finding is relevant to the sensory context of a movement, but an effect on emotional discrimination or memory does not directly measure force accuracy. Nasal and oral breathing also differ in more than a label attached to phase; any transfer to motor tasks must preserve the conditions under which the neural effect was observed.

Herrero and colleagues used intracranial recordings to distinguish natural breathing, voluntary pacing and attention to breathing. These conditions engaged overlapping but distinguishable patterns of respiratory-neural coherence (Herrero et al., 2018). The distinction matters when comparing a spontaneous phase preference with an instruction to coordinate a movement consciously with a breath. Voluntary pacing changes the task itself. It can add monitoring and temporal control demands that are absent when breathing remains unattended.

Noninvasive work further prevents confining respiratory modulation to olfactory structures. Kluger and Gross identified respiration-related modulation of oscillatory activity across a distributed resting-state network (Kluger and Gross, 2021). Kluger and colleagues then linked respiratory phase, posterior alpha activity and sensitivity in a near-threshold visual detection task (Kluger et al., 2021). Such findings make respiratory variation in visual sampling plausible during target tracking. They do not show that the same phase maximizes detection, action initiation and correction of a force deviation. The movement may require those processes at different times.

Perl and colleagues observed alignment of nasal inhalation with non-olfactory task onset and examined its association with visuospatial performance (Perl et al., 2019). Johannknecht and Kayser, using six sensory-cognitive tasks, found respiratory alignment with stimulus presentation and responses, with more consistent relationships for reaction time than response accuracy (Johannknecht and Kayser, 2022). The contrast is informative rather than contradictory: a phase associated with incoming information can differ from a phase associated with making a response. In an extended manual task, repeated sensory acquisition and repeated correction can occupy both phases within the same trial.

Somatosensory evidence adds a further qualification. Grund and colleagues showed relationships among respiratory alignment, cardiac timing and conscious tactile detection (Grund et al., 2022). Their results suggest that respiratory and cardiac coordinates should not be treated as interchangeable, even though they can covary. For kinesiology, the resulting prediction is limited: tactile information used to regulate grip may be subject to bodily timing influences. Direct measurement of grip regulation is still necessary. Collectively, the neural literature supports a distributed, task-sensitive influence; it does not identify a phase in which every component of precision control improves together.

MECHANICS AND VENTILATION ARE ALTERNATIVE ROUTES TO THE SAME OBSERVED ERROR

Respiration can affect a manual task through movement of the body as well as through neural timing. Baweja and colleagues found that higher respiratory amplitude altered slow force fluctuations, and their measurements did not identify a single complete explanation in agonist surface electromyography or visuomotor correction (Baweja et al., 2011). This leaves mechanical transmission as a relevant possibility, not a proven exclusive mechanism. An unsupported arm and an externally stabilized forearm should not be assumed to experience the same transmission of thoracic displacement.

The diaphragm itself also cannot be assigned one fixed relationship to a respiratory phase during every action. Sembera and colleagues combined ultrasonographic diaphragm assessment with load-lifting conditions and documented postural displacement as well as respiratory excursion (Sembera et al., 2022). A movement task can therefore alter the mechanical meaning of a chest or abdominal trace. An apparent phase association could reflect changes in support, postural demand or the shape of the recorded signal, especially when the sensor moves with the task.

Ventilation supplies another route. Yunoki and colleagues compared carbon-dioxide conditions during repeated knee extensions while matching respiratory frequency and tidal volume. Force coefficient of variation differed between hypercapnia and hypocapnia; within the hypercapnic condition, its change also correlated positively with the change in end-tidal carbon dioxide (Yunoki et al., 2023). Thus breathing-pattern similarity does not guarantee equivalent gas physiology. The small male sample and lower-limb task limit transfer to fine manual control, but the study directly motivates gas measurement when rate or depth is manipulated.

Cerebral perfusion is sensitive to arterial blood gases in interaction with other physiological controls (Willie et al., 2014). Respiratory frequency is not alveolar ventilation, and uncalibrated belt amplitude is not tidal volume. End-tidal carbon dioxide can characterize ventilatory differences in an appropriate experiment, with its measurement limitations documented; it is not a direct readout of neural excitability. Without such measurements, an observed breathing-condition difference can remain compatible with gas-mediated, attentional and mechanical explanations.

Measurement choice must match the claim. Contact-based respiratory techniques differ in their working principles and susceptibility to movement artifacts (Massaroni et al., 2019). A belt can be useful for identifying cycles, but an airflow signal is needed when the claim specifically concerns inspiratory versus expiratory flow or nasal versus oral routing. Recording more than one respiratory signal allows phase landmarks to be checked rather than inferred from a single convention. Synchronization with force and movement records is essential because a phase assigned at a visual cue cannot silently substitute for phase at force onset.

A PHASE PREFERENCE AND A PHASE-DEPENDENT ERROR ARE MATHEMATICALLY DIFFERENT QUANTITIES

Let ϕ denote respiratory phase at action onset on $[0, 2\pi)$, and let Y be a specified execution-error outcome. Define $p(\phi)$ as the density of observed onset phases and $m(\phi) = \mathbb{E}[Y \mid \phi]$ as the conditional mean error. The overall error is

$$\mathbb{E}[Y] = \int_0^{2\pi} m(\phi)p(\phi) d\phi. \quad (1)$$

Clustering of onsets changes p ; it does not establish the direction or magnitude of m . A performer could prefer expiration while producing equal errors in both phases. Alternatively, the person could preferentially choose a phase associated with lower error. Distinguishing those possibilities requires measuring error, not simply the number of actions within a phase.

For two breathing conditions, A and B , subtraction and addition of the same term give the exact identity

$$\mathbb{E}[Y_A] - \mathbb{E}[Y_B] = \int_0^{2\pi} \{m_A(\phi) - m_B(\phi)\}p_B(\phi) d\phi + \int_0^{2\pi} m_A(\phi)\{p_A(\phi) - p_B(\phi)\} d\phi. \quad (2)$$

The first term compares conditional error at condition B 's onset distribution; the second describes redistribution of onset phases using condition A 's error function. The allocation depends on the reference, although the total does not. Estimation requires common phase support: where condition A never generates an onset, m_A cannot be estimated for condition B without extrapolation. Analyses should therefore show both phase distributions and restrict contrasts to supported regions or state the required model assumptions. These are descriptive identities, not new estimators or causal decompositions. Voluntary condition choice, attention or task difficulty can influence both phase and error.

Observed action counts also require a time denominator. If N_b actions occur in phase bin b during H_b seconds when an action could actually be initiated, an exposure-adjusted initiation rate is

$$\hat{\lambda}_b = \frac{N_b}{H_b}. \quad (3)$$

The denominator should exclude intervals in which the task prohibits action, including imposed waiting periods. If expiration occupies more eligible time, it can contain more actions even under an equal initiation rate. This is a general interpretive distinction, not an allegation that the cited studies neglected phase normalization. In precision experiments it is useful to retain both the observed onset distribution and the eligible-time distribution so that selection and opportunity remain separately visible.

DURATION AND LAG DETERMINE WHAT AVERAGING PRESERVES

Onset phase compresses the respiratory trajectory of a sustained contraction into one number. Let respiratory phase $\theta(t)$ have zero at inspiratory-flow onset and increase to 2π at the next inspiratory onset. For a fixed period T , $\theta(t) = \phi_0 + 2\pi t/T$ during an execution interval of length D . Expiratory onset need not occur at π : unequal inspiratory and expiratory durations must be measured. A belt-based landmark convention must be checked against airflow before it is interpreted in this way.

Consider the stipulated force-error signal

$$e(t) = b + a \cos\{\theta(t) - \delta\}, \quad 0 \leq t \leq D, \quad (4)$$

where b is constant target bias, $a \geq 0$ is perturbation amplitude and δ is the respiratory phase of maximum positive perturbation. Thus δ permits a lag between the respiratory reference and force fluctuation. Both b and a have force units; phases are in radians. Set $q = D/T > 0$ and $\beta = \phi_0 - \delta$. Constant amplitude, bias, period and lag, linear addition and uniformly advancing phase are assumptions, not established physiological properties.

Direct integration gives the signed interval mean

$$\bar{e}_D = b + aS_1 \cos(\beta + \pi q), \quad S_1 = \text{sinc}(\pi q), \quad \text{sinc}(x) = \frac{\sin x}{x}. \quad (5)$$

The signed phase term is attenuated by S_1 and changes sign across its zeros. Applying $\cos^2 x = (1 + \cos 2x)/2$ yields the mean-square error for any duration:

$$M_D = \frac{1}{D} \int_0^D e(t)^2 dt = b^2 + 2baS_1 \cos(\beta + \pi q) + \frac{a^2}{2} \{1 + S_2 \cos(2\beta + 2\pi q)\}, \quad S_2 = \text{sinc}(2\pi q). \quad (6)$$

Root-mean-square error is $\sqrt{M_D}$, and temporal variance about the interval mean is $M_D - \bar{e}_D^2$. Eq. (6) retains the bias-oscillation cross-term; omitting it would incorrectly describe partial-cycle error when $b \neq 0$. For $D = nT$, with n any positive integer, both sinc terms vanish:

$$\bar{e}_{nT} = b, \quad M_{nT} = b^2 + \frac{a^2}{2}, \quad \text{Var}_t(e) = \frac{a^2}{2}. \quad (7)$$

Complete-cycle averaging removes the harmonic from signed bias while preserving its squared contribution. At half-integer q , S_2 also vanishes; for zero bias this makes mean-square error independent of onset phase even when the signed mean remains phase dependent. With nonzero bias, the cross-term generally prevents that conclusion.

The prediction concerns a measured periodic component and a specified averaging window. Phase dependence of signed bias should weaken near complete-cycle durations while respiratory-frequency fluctuation can persist. A larger analysis window does not necessarily improve control: sinc attenuation is nonmonotonic, task tolerance may be violated within the interval, and other errors are absent from this calculation. Drift, changing lag, feedback correction and irregular phase speed can alter the prediction.

For an irregular cycle, the time average of $\cos\{\theta(t) - \delta\}$ need not vanish over one phase revolution, because phase occupancy is uneven. Integration over recorded time, rather than forcing a fixed-period formula onto the signal, is required. Additional integer harmonics with constant coefficients would also cancel from signed means over full periods; cancellation is therefore not evidence that the physical perturbation is sinusoidal. The contribution is a measurement interpretation under explicit assumptions, not identification of the perturbation's biological source.

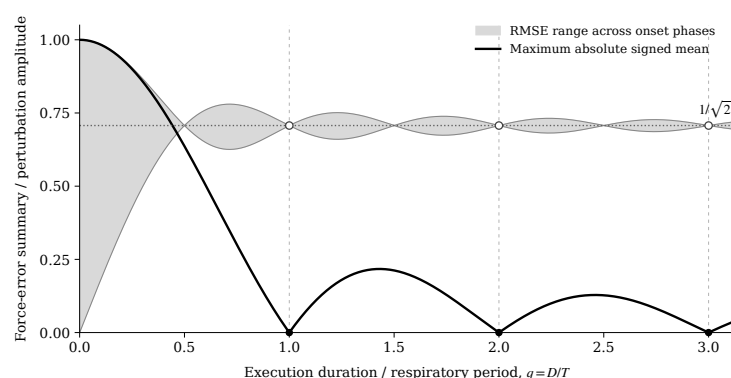


FIGURE 1. DURATION-DEPENDENT PHASE SENSITIVITY OF SIGNED AND SQUARED FORCE ERROR

Exact functions for Eq. (4) with $b = 0$, $a > 0$ and fixed period. The dark curve is the largest absolute signed mean over all onset phases, $|\bar{e}_D|_{\max}/a = |\text{sinc}(\pi q)|$. The grey band spans the smallest and largest normalized root-mean-square error (RMSE) over those phases, $[\{1 \mp |\text{sinc}(2\pi q)|\}/2]^{1/2}$. Complete-cycle durations $q = 1, 2, 3$ have zero signed mean but RMSE $1/\sqrt{2}$. The dotted line marks that value. The band is an exact phase range, not a confidence interval. The zero-duration endpoint denotes the continuous limit. No participant values are shown.

DISCUSSION

EXECUTION EXPOSURE LINKS EVIDENCE TO A MEANINGFUL MOTOR OUTCOME

The literature supports specific coordination benefits and several routes through which respiration can alter performance. Its endpoints must nevertheless remain separate. The contribution of the present analysis is to connect action selection with conditional error and to show how the chosen execution interval changes the error being summarized. It does not introduce a new breathing–brain mechanism. Unlike broad accounts of respiration and cognition (Heck et al., 2022; Goheen et al., 2023), it makes the force target, interval duration and error definition central to interpreting a respiratory association.

For a brief pulse, onset phase can approximate respiratory exposure during most of the movement if duration is short relative to the breath. For a sustained hold, respiratory phase traverses several cycles while feedback corrections continue. Recording D/T together with the phase trajectory specifies that difference; it does not require every trial to have the same respiratory period. Analysis windows should follow the motor question and be fixed before inspecting phase effects.

Mean signed error measures bias relative to the target. RMSE combines bias and temporal deviations; temporal standard deviation measures within-interval fluctuation about its mean. Across-trial endpoint standard deviation measures consistency between repetitions. These quantities should have separate symbols and units. For grip or tracking, an additional outcome can be time outside a prespecified tolerance band. Such a threshold must reflect the action's requirements rather than being chosen to favour one phase. A mean-correct signal can still intermittently exceed an acceptable force or trajectory limit.

MECHANISTIC CONTRASTS AND FALSIFIABLE PREDICTIONS

Table 1 specifies four comparisons and their primary readouts. They are experimental proposals, not completed protocols. Each would require participant-level sample planning from a justified effect and uncertainty target, preregistered outcomes, and ethics review appropriate to the actual procedures. A large number of repeated events should not be used to justify a small independent sample.

For phase-triggered cues, phase should be assigned from synchronized respiratory recordings rather than cue scheduling alone. Participants can anticipate regularly triggered events, so foreperiod distributions and preparation opportunities must be balanced as far as the crossed design permits. Actual achieved phase and any departures from the respiratory instruction should be reported. Random assignment to a cue phase estimates the effect of that cue schedule; it does not automatically estimate the effect of spontaneously choosing the same movement-onset phase.

The duration test should compare prespecified windows around complete cycles while preserving contraction demand and checking drift or fatigue. Conditioning window length on the observed breath can itself change what data enter an analysis. A fixed-duration sensitivity analysis and a cycle-aligned analysis should therefore be distinguished. Coordination need not be eliminated: Hessler and Amazeen show that motor–respiratory ratios can be learned (Hessler and Amazeen, 2014), while the tracking and handgrip findings (Krupnik et al., 2015; Li et al., 2024) justify testing helpful as well as disruptive coupling. The decisive question is whether a particular organization improves the designated endpoint.

TABLE 1. DISCRIMINATING COMPARISONS FOR RESPIRATORY ASSOCIATIONS IN PRECISION MOVEMENT

Hypothesis and contrast	Primary outcome and verification	Prediction and competing interpretation
Mechanical transmission: supported versus unsupported forearm at matched target force	Respiratory-frequency force amplitude; synchronized trunk/arm motion, surface electromyography and airflow	Reduced force modulation accompanying reduced transmitted motion supports a mechanical contribution. Changed recruitment or feedback must be assessed before attributing the difference exclusively to mechanics
Sensory versus execution timing: cross target-presentation phase with delayed force-onset phase	RMSE over a fixed execution interval; actual phase at stimulus, movement and throughout contraction	An effect tied to stimulus phase supports sensory timing; an effect tied to execution after comparable preparation supports a later process. Delay, cue predictability and task difficulty must be balanced
Ventilatory pathway: compare respiratory conditions while recording rate, volume and end-tidal carbon dioxide	Prespecified force-error contrast, with gas and movement measurements	A phase effect remaining after matched measured ventilation is consistent with another pathway, but does not prove a neural cause. Matching rate alone is insufficient; causal mediation requires a separate design
Interval averaging: analyse prespecified durations around individual complete cycles	Signed mean, RMSE and respiratory-frequency force component; measured phase trajectory	Vanishing phase dependence of signed mean with persistent squared error and respiratory modulation matches averaging. Loss of the periodic component requires another explanation; persistent bias modulation at complete cycles contradicts the stationary zero-mean harmonic model

RMSE: root-mean-square error. These are discriminating tests, not uniquely identifying interventions. Primary outcomes and duration contrasts require specification before data inspection.

STATISTICAL INFERENCE MUST PRESERVE THE LEVEL OF OBSERVATION

Breaths and movement repetitions are nested within people. A large number of synchronized events does not substitute for a large number of independent participants. Phase-dependent error analyses should therefore retain participant-level variation, for example through prespecified hierarchical models. Sine and cosine terms can describe a first-harmonic relationship with phase, while higher harmonics should be justified by task behavior or an explicit prior hypothesis. The two preferred phase relationships identified under some tracking demands (Krupnik et al., 2015) caution against assuming that every association has only one maximum per cycle.

For self-initiated actions, phase-dependent initiation should be assessed against eligible time, including the waiting and refractory structure of the task. For cued actions, inference should distinguish phase at cue onset from phase at movement onset. Reaction-time distributions are commonly skewed, and error distributions can contain both systematic bias and heterogeneous variance. The chosen statistical family should reflect those properties rather than treating latency, signed error and squared error as interchangeable normal outcomes. Uncertainty should be expressed for the specified endpoint and contrast, not inferred from the apparent smoothness of a phase-averaged curve.

Surrogate analyses can help evaluate synchronization, but indiscriminate shuffling destroys task timing and can produce an inappropriate reference distribution. A useful surrogate preserves relevant serial structure and the timing opportunities that could generate alignment. Similarly, correlations between respiratory coherence and performance do not establish that deliberately increasing coherence will improve performance. Instruction, practice, fatigue and task difficulty can influence both. A causal recommendation requires intervention evidence for the actual movement outcome.

Missing cycles and breath holds deserve explicit treatment. A hold is not simply an extremely long inspiratory or expiratory phase to which ordinary cyclic formulas can be applied. Movement-contaminated belt segments should be identified using a prespecified rule, and their distribution across task conditions should be examined. Excluding difficult trials preferentially from one phase can change the conditional error function. Sensitivity analysis should consequently show whether conclusions survive reasonable landmark uncertainty and artifact handling, with those choices documented before claims about phase superiority are made.

IMPLICATIONS AND LIMITS FOR BREATHING INSTRUCTIONS

Breathing instructions can serve aims other than immediate precision. Balban and colleagues investigated brief structured breathing practices and found effects on mood and physiological arousal (Balban et al., 2023). Those endpoints are meaningful, but they do not establish the respiratory phase that minimizes execution error in a sport skill. An intervention intended to reduce distress before performance should be evaluated separately from an instruction intended to stabilize the hand during performance. The timing of the intervention relative to the task is part of the explanation.

This separation is particularly relevant when a movement must be both fast and accurate. Frequency manipulations can affect initiation, discomfort and emotional state; the neutral-image error comparison requires cautious interpretation because its interaction test was nonsignificant (Buchanan and Janelle, 2022). The present analysis therefore supports outcome-specific evaluation of an instruction, including the possibility of a speed-accuracy trade-off. It does not support prescribing fast breathing for rapid sports or slow breathing for accurate sports on the basis of a laboratory pinch task. Sport-specific validation requires the actual demands, tolerances and preparation constraints of that skill.

Several limitations restrict the conclusions. Ranked web retrieval, a fixed historical publication window and single-workflow selection may omit relevant studies. No pooled estimate or population-level certainty rating is provided.

Abstract-only access for three performance reports prevents full assessment of their methods, and reporting discrepancies in another reduce its quantitative weight. Small laboratory tasks differ from whole-body sporting actions. Neural observations in clinical intracranial samples inform possible mechanisms but do not supply population estimates for healthy athletes. Finally, the sinusoidal calculation establishes a measurement property under defined assumptions, not the existence or amplitude of that perturbation in every participant.

Within those limits, the article supplies a defensible correspondence between kinesiology and neighboring sciences. Respiratory neuroscience becomes useful to movement science when its phase relationships are connected to measurable force or trajectory errors. Respiratory mechanics becomes useful when transmitted body motion is assessed alongside the motor endpoint. Statistical reasoning becomes useful when it separates action opportunity, selection and execution. The resulting account is narrow enough to test and broad enough to prevent physiologically different studies from being merged into one unsupported rule.

CONCLUSIONS

Human experiments support respiratory associations with force steadiness, action timing, tracking precision and handgrip endurance, including beneficial coordination in specific tasks. They do not identify a universally optimal respiratory phase for execution accuracy. Interpreting a precision action requires its target, respiratory manipulation, temporal anchor and execution interval to be specified together. Established conditional-expectation relationships separate onset selection from conditional error; exact periodic-error calculations explain why complete-cycle signed averaging can conceal persistent fluctuation. These calculations supply falsifiable measurement predictions under stated assumptions, not evidence of a breathing treatment. Comparisons that measure sensory timing, movement transmission, ventilation and within-interval error can give neighbouring sciences a concrete role in kinesiology while preserving the difference between a candidate mechanism and a demonstrated task benefit.

DECLARATIONS

AUTHOR CONTRIBUTIONS

All authors contributed equally and all authors read and approved the final version of this manuscript.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest related to this study.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

FUNDING

This research received no external funding.

REFERENCES

1. Ashhad S, Kam K, Del Negro CA, Feldman JL. Breathing rhythm and pattern and their influence on emotion. *Annual Review of Neuroscience*. 2022;45:223–247.
2. Balban MY, Neri E, Kogon MM, Weed L, Nouriani B, Jo B, et al. Brief structured respiration practices enhance mood and reduce physiological arousal. *Cell Reports Medicine*. 2023;4(1):100895.
3. Baweja HS, Patel BK, Neto OP, Christou EA. The interaction of respiration and visual feedback on the control of force and neural activation of the agonist muscle. *Human Movement Science*. 2011;30(6):1022–1038.
4. Buchanan TL, Janelle CM. Fast breathing facilitates reaction time and movement time of a memory-guided force pulse. *Human Movement Science*. 2021;76:102762.

5. Buchanan TL, Janelle CM. Emotions and ensuing motor performance are altered by regulating breathing frequency: implications for emotion regulation and sport performance. *Frontiers in Psychology*. 2022;13:963711.
6. Enoka RM, Farina D. Force steadiness: from motor units to voluntary actions. *Physiology*. 2021;36(2):114–130.
7. Goheen J, Anderson JAE, Zhang J, Northoff G. From lung to brain: respiration modulates neural and mental activity. *Neuroscience Bulletin*. 2023;39(10):1577–1590.
8. Grund M, Al E, Pabst M, Dabbagh A, Stephani T, Nierhaus T, et al. Respiration, heartbeat, and conscious tactile perception. *Journal of Neuroscience*. 2022;42(4):643–656.
9. Heck DH, Correia BL, Fox MB, Liu Y, Allen M, Varga S. Recent insights into respiratory modulation of brain activity offer new perspectives on cognition and emotion. *Biological Psychology*. 2022;170:108316.
10. Herrero JL, Khuvis S, Yeagle E, Cerf M, Mehta AD. Breathing above the brain stem: volitional control and attentional modulation in humans. *Journal of Neurophysiology*. 2018;119(1):145–159.
11. Hessler EE, Amazeen PG. Learning and transfer in motor-respiratory coordination. *Human Movement Science*. 2014;33:321–342.
12. Johannknecht M, Kayser C. The influence of the respiratory cycle on reaction times in sensory-cognitive paradigms. *Scientific Reports*. 2022;12:2586.
13. Kluger DS, Gross J. Depth and phase of respiration modulate cortico-muscular communication. *NeuroImage*. 2020;222:117272.
14. Kluger DS, Gross J. Respiration modulates oscillatory neural network activity at rest. *PLOS Biology*. 2021;19(11):e3001457.
15. Kluger DS, Balestrieri E, Busch NA, Gross J. Respiration aligns perception with neural excitability. *eLife*. 2021;10:e70907.
16. Krupnik V, Nietzold I, Bartsch B, Rassler B. The effect of motor-respiratory coordination on the precision of tracking movements: influence of attention, task complexity and training. *European Journal of Applied Physiology*. 2015;115(12):2543–2556.
17. Li S, Park WH, Borg A. Phase-dependent respiratory-motor interactions in reaction time tasks during rhythmic voluntary breathing. *Motor Control*. 2012;16(4):493–505.
18. Li Z, Li W, Lin PJ, Jia T, Ji L, Li C. Motor-respiratory coupling improves endurance performance during rhythmic isometric handgrip exercise. *Medicine & Science in Sports & Exercise*. 2024;56(3):536–544.
19. Massaroni C, Nicolò A, Lo Presti D, Sacchetti M, Silvestri S, Schena E. Contact-based methods for measuring respiratory rate. *Sensors*. 2019;19(4):908.
20. Park HD, Barnoud C, Trang H, Kannape OA, Schaller K, Blanke O. Breathing is coupled with voluntary action and the cortical readiness potential. *Nature Communications*. 2020;11:289.
21. Park HD, Piton T, Kannape OA, Duncan NW, Lee KY, Lane TJ, et al. Breathing is coupled with voluntary initiation of mental imagery. *NeuroImage*. 2022;264:119685.
22. Perl O, Ravia A, Robinson M, Eisen A, Soroka T, Mor N, et al. Human non-olfactory cognition phase-locked with inhalation. *Nature Human Behaviour*. 2019;3(5):501–512.
23. Sembera M, Busch A, Kobesova A, Hanychova B, Sulc J, Kolar P. Postural-respiratory function of the diaphragm assessed by M-mode ultrasonography. *PLOS ONE*. 2022;17(10):e0275389.
24. Willie CK, Tzeng YC, Fisher JA, Ainslie PN. Integrative regulation of human brain blood flow. *Journal of Physiology*. 2014;592(5):841–859.
25. Yunoki T, Zang K, Hatano K, Matsuura R, Ohtsuka Y. Relationship between disturbances of CO₂ homeostasis and force output characteristics during isometric knee extension. *Respiratory Physiology & Neurobiology*. 2023;315:104119.
26. Zelano C, Jiang H, Zhou G, Arora N, Schuele S, Rosenow J, et al. Nasal respiration entrains human limbic oscillations and modulates cognitive function. *Journal of Neuroscience*. 2016;36(49):12448–12467.