

TIMING DIRECTIONAL INFORMATION BEFORE A TURN: AN OVERGROUND PROTOCOL WITH STOP-INCLUSIVE PROGRESS MEASUREMENT

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Received: 23 January 2024 Revised: 18 April 2024 Accepted: 12 May 2024 Published: 20 June 2024

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ABSTRACT

Directional signs identify a route, but correct branch selection alone does not describe walking before a junction. This article derives a stop-inclusive progress measure and specifies a randomized overground protocol for directional-cue timing. The reference and near-turn gates each span 4 m, at 20–16 m and 6–2 m before fixed turn entry. Gate speed equals distance divided by complete elapsed traversal time, including pauses and reversals. Relative suppression is $M = 1 - v_{\text{near}}/v_{\text{ref}}$. For constant progress at 1.2 m/s outside one of sixteen 0.25 m bins, a five-second pause gives $M = 0.060$ under an arithmetic mean of bin speeds and $M = 0.600$ under complete-gate timing. The arithmetic calculation approaches a 6.25% ceiling for an indefinitely long single-bin pause. The protocol crosses arrow onset at 14 or 7 m before turn entry, 45° or 90° turns, and an upcoming branch either unknown or known before departure. Six traversals per cell yield 48 trials per participant, balanced by direction. A trial score assigns M to completed near gates and a value of one to observed behavioral noncompletion; technical loss remains missing. The primary contrast compares late with early arrow access in unknown-route trials. A timing-by-knowledge contrast, route errors, stop durations, total approach time and head–thorax orientation address distinct aspects of the response. The numerical values evaluate the derived equations. Recruitment and human measurement have not taken place; the protocol requires prospective feasibility and reliability testing.

Keywords: directional-cue timing; overground walking; gate traversal time; pedestrian turning; route knowledge; head–thorax orientation.

INTRODUCTION

A pedestrian approaching an unfamiliar junction must acquire a direction, choose an exit and prepare the body to turn. Route-choice research describes perception, integration and decision-making within that journey (Tong and Bode, 2022). A correct exit can nevertheless follow a prolonged stop, and uninterrupted walking can lead to a wrong exit. Branch accuracy and continuity of movement therefore need separate measurements.

Brunyé and colleagues examined guidance requests and anticipatory heading changes during desktop navigation (Brunyé et al., 2018). Giannopoulos and colleagues related the distance at which navigation instructions were requested to participant and environmental characteristics in a virtual environment (Giannopoulos et al., 2017). Decision-point complexity also depends on spatial configuration and the wayfinder (De Cock et al., 2021). These studies place directional decisions upstream of junction arrival, but physical walking introduces step placement, body rotation and interruption of forward progress.

The protocol compares the same arrow, exit direction and nominal turning arc when the arrow first appears at 14 or 7 m before turn entry. Walking is measured at identical physical positions in both conditions. A second comparison supplies

the branch before departure, allowing the arrow event to occur without revealing a new route. This separates the response to display timing from its dependence on advance branch knowledge, while retaining the possibility that knowledge also changes motor preparation.

The measurement question is whether elapsed time lost during a pause survives the averaging procedure. An arithmetic average of equal-distance bin speeds can assign a long interruption little weight. Complete-gate timing retains every second between entry and exit. The ensuing analysis addresses three quantities: the local progress difference between cue timings, its dependence on advance route knowledge, and the difference in total approach time. None alone establishes cognitive burden or walking safety.

ROUTE KNOWLEDGE AND ANTICIPATORY LOCOMOTION

BRANCH KNOWLEDGE AND ARROW RECOGNITION

Wayfinding strategies vary with environmental knowledge (Hegarty et al., 2023). Practice changes visual attention (Geisen et al., 2021), and the value assigned to environmental information can change across successive route choices (Tong and Bode, 2021). Course familiarity and knowledge of the next branch are therefore distinct: a participant can know the junction layout while remaining unaware of the exit required on the current trial. The trial schedule varies direction, conceals upcoming cue timing and retains order for analysis.

Navigators can weight landmarks and directional instructions differently under spatial uncertainty (Tenbrink et al., 2020; Brunyé et al., 2015). Here, a single arrow identifies one branch; its content is held constant within each matched timing comparison. Randomization changes the first position at which that arrow becomes visible. Electrical onset, visual recognition and confidence in the route are separate events. A static recognition test establishes eligibility, and an after-trial recognition question checks whether the walking participant identified the displayed arrow.

VISUAL GUIDANCE AND TURN PREPARATION

Forward visual information guides foot placement over complex terrain (Matthis and Fajen, 2014), and gaze behavior depends on the terrain traversed (Matthis et al., 2018). Head movements are coordinated with other body segments (van Andel et al., 2023); gaze-gait responses during perturbed walking also depend on the concurrent task (Müller et al., 2023). These observations justify measuring orientation before turn entry. Head-thorax yaw separation describes segmental alignment, however, and cannot locate gaze or quantify mental workload.

Turn kinematics depend on the maneuver and testing environment (Pavčić et al., 2014). Dual-task responses vary with walking demand and input modality (Gupta et al., 2023); findings in older adults walking in real environments involve conditions outside this healthy-adult laboratory protocol (Zukowski et al., 2021). Timing comparisons use identical nominal geometry. Actual curvature and the position of trunk rotation remain outcomes because a cue can change when or how preparation begins. Adjusting the primary effect for those post-cue responses would remove part of the effect under investigation.

STOP-INCLUSIVE PROGRESS MEASUREMENT

FIXED GATES AND TRAVERSAL TIME

Let s be signed distance along the marked approach centreline, with $s = 0$ at the nominal beginning of the turning arc. The origin is fixed by the floor markings before walking. It is independent of observed head rotation, trunk rotation or trajectory departure. The reference gate is $[-20, -16]$ m and the near-turn gate is $[-6, -2]$ m; both have length $L = 4$ m.

For a completed gate, T_g runs from the first valid entry-plane crossing to the first subsequent valid exit-plane crossing. Crossings must occur inside the 2 m-wide marked approach. The clock continues through pauses, reversals, temporary departures and repeated entry crossings. Gate speed is

$$v_g = \frac{L_g}{T_g}. \quad (1)$$

This quantity measures net progress through a fixed gate. It does not use the length of a meandering trajectory; a detour can lower gate speed while instantaneous walking speed remains unchanged.

Relative near-turn suppression is

$$M = 1 - \frac{v_{\text{near}}}{v_{\text{ref}}} = 1 - \frac{T_{\text{ref}}}{T_{\text{near}}}, \quad (2)$$

where the time-ratio expression requires equal gate lengths. Equal speeds give $M = 0$; slower near-turn progress gives $M > 0$; faster progress gives $M < 0$. Negative values are retained. Balance, energy expenditure and route accuracy are not contained in this ratio.

The nominal cue horizon is $h = |s_c|/v_{\text{ref}}$. At $v_{\text{ref}} = 1.2$ m/s, onset at $s_c = -14$ and -7 m corresponds to 11.67 and 5.83 s of travel at unchanged speed. These quotients do not measure reading time or the actual time remaining after the cue changes walking.

EXACT RESPONSE TO A SINGLE-BIN PAUSE

Divide a gate of length L into N equal bins, each of width $d = L/N$. Let progress be constant at v_0 except for an additional pause of duration p inside one bin. The interrupted bin takes $d/v_0 + p$ seconds. An arithmetic average of bin speeds and the complete-gate calculation give

$$\bar{v}_{\text{space}} = \frac{(N-1)v_0 + d/(d/v_0 + p)}{N}, \quad (3)$$

$$v_{\text{gate}} = \frac{L}{L/v_0 + p}. \quad (4)$$

Their suppression relative to v_0 is

$$M_{\text{space}} = \frac{1}{N} \left(1 - \frac{d/v_0}{d/v_0 + p} \right), \quad \lim_{p \rightarrow \infty} M_{\text{space}} = \frac{1}{N}, \quad (5)$$

$$M_{\text{gate}} = \frac{p}{L/v_0 + p}, \quad \lim_{p \rightarrow \infty} M_{\text{gate}} = 1. \quad (6)$$

For sixteen bins, the spatial arithmetic average cannot exceed 6.25% suppression when the interruption is confined to one bin, regardless of its duration. Complete-gate suppression approaches 100%. The difference follows from the weighting: each spatial bin receives equal weight despite unequal traversal times. The harmonic mean of equal-distance bin speeds equals complete-gate speed only when their times partition the entire traversal, including boundary pauses and reversals.

TABLE 1. CLOSED-FORM EVALUATIONS FOR A 4 M GATE, SIXTEEN 0.25 M BINS AND $v_0 = 1.2$ M/S. EACH ROW ADDS THE STATED PAUSE TO ONE BIN; THE VALUES ARE ALGEBRAIC CALCULATIONS.

Pause (s)	Spatial mean (m/s)	Gate speed (m/s)	M_{space}	M_{gate}
0	1.200	1.200	0.000	0.000
0.5	1.147	1.043	0.044	0.130
2	1.132	0.750	0.057	0.375
5	1.128	0.480	0.060	0.600
30	1.126	0.120	0.062	0.900

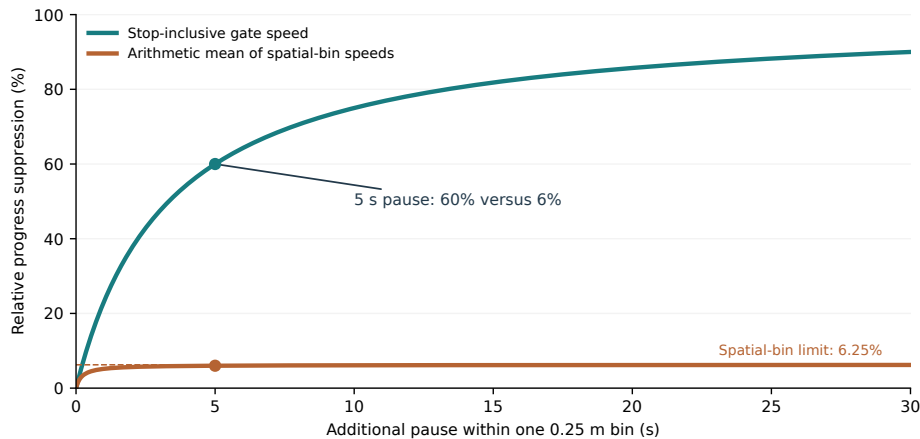


FIGURE 1. SUPPRESSION CALCULATED FROM EQUATIONS 5 AND 6 AS THE ADDITIONAL PAUSE INCREASES FROM 0 TO 30 S. THE ARITHMETIC MEAN APPROACHES $1/16$; COMPLETE-GATE SUPPRESSION RETAINS THE FULL ADDED TIME. THE MARKED FIVE-SECOND PAUSE GIVES 6% AND 60%, RESPECTIVELY. THE CURVES EVALUATE THE EQUATIONS AND CONTAIN NO PARTICIPANT TRAJECTORIES.

NONCOMPLETION AND THE PRIMARY TRIAL SCORE

Analyzing only completed near gates can exclude a behavior that differs between cue timings. The primary score is

$$Q = \begin{cases} M, & \text{near gate entered and completed within the time limits,} \\ 1, & \text{observed behavioral noncompletion.} \end{cases} \quad (7)$$

Near-gate entry must occur within 45 s of reference-gate exit, followed by completion within 30 s of near-gate entry. Behavioral noncompletion means an observed failure to meet either limit, or departure from the task that prevents completion. An unreadable recording, equipment cancellation or consent withdrawal does not establish behavioral failure. Such trials are technically missing or withdrawn.

Assigning $Q = 1$ specifies a noncompletion penalty; it does not assign an estimated walking speed. Let $C = 1$ denote completion. The mean score decomposes as

$$E(Q) = P(C = 0) + P(C = 1)E(M \mid C = 1). \quad (8)$$

Both the noncompletion proportion and the mean M among completers accompany every condition mean. Completer-only comparisons remain descriptive because completion can depend on the assigned cue. Sensitivity analyses vary the two deadlines and the penalty.

COURSE AND TRIAL PROCEDURE

PHYSICAL LAYOUT AND ARROW DISPLAY

The course requires a 25 m straight approach, 2 m wide, and a level turning area at least 8 m by 8 m. Walking begins 5 m before reference-gate entry. Four marked centrelines permit left and right turns of 45° and 90° . Each arc starts at $s = 0$, has radius 2 m and joins a straight exit of at least 6 m. All branches remain visible, and one participant walks at a time. The nominal arc lengths are $\pi/2$ and π m, respectively. Both arcs have curvature 0.5 m^{-1} : greater turn angle increases arc length and heading change, but does not imply greater nominal peak curvature. Actual trajectories within the route width are retained.

An overhead display is centred above $s = 0$, with its lower edge at least 2.3 m above the floor. The active face is 0.6 m square and presents one arrow 0.35 m wide. Diagonal arrows identify 45° exits and horizontal arrows identify 90° exits. A uniform dark-gray face precedes onset. Setup requirements are arrow luminance 80 cd/m^2 , background luminance 8 cd/m^2 and room illuminance $300 \pm 30 \text{ lx}$. Tracked passage through $s = -14$ or -7 m triggers the arrow, which persists until trial end. Display location, arrow content and lighting remain identical within each timing pair. These dimensions and light levels specify the apparatus to be installed and checked.

At each trigger position, a standing participant identifies twelve randomly oriented arrows at natural head height. All twelve answers must be correct at each distance before eligibility is confirmed. Corrected vision, recognition accuracy and standing eye height are recorded. After each walking trial, a four-choice question asks which arrow appeared. The question occurs after walking to avoid imposing a simultaneous verbal task; it checks arrow identity rather than recognition latency.

FACTORIAL SCHEDULE AND INSTRUCTIONS

The within-participant design crosses two cue timings, two turn angles and two knowledge conditions. Each of the eight cells contains six trials, comprising three left and three right turns. The 48 traversals form six blocks of eight, each containing one trial per cell. Direction allocation across blocks provides the within-cell balance. A computer-generated seed independently permutes the eight cells in each block. The allocation record retains the seed, cell, direction, release time and arrow image. Participants and movement assessors do not receive the upcoming timing label.

For an unknown-route trial, the instruction is: "Walk comfortably along the approach; the display will identify your exit." For a known-route trial, the assessor names the required angle and direction before departure. The participant repeats the instruction correctly before starting. The arrow image and onset then match those in the unknown-route condition. Advance knowledge removes the arrow's role in revealing the branch, while allowing knowledge to affect preparation before onset.

The controller releases the scheduled timing label only after the reference gate is completed at $s = -16$ m. Release does not involve another random draw. A reference traversal slower than 0.4 m/s , or containing a stop of at least 0.5 s , is repeated before release with the same concealed cell. Two consecutive invalid traversals trigger rest and eligibility reassessment. The speed floor restricts denominator values; it is not a safety threshold. Slow walking, stopping and wrong exits after cue onset do not justify outcome exclusion.

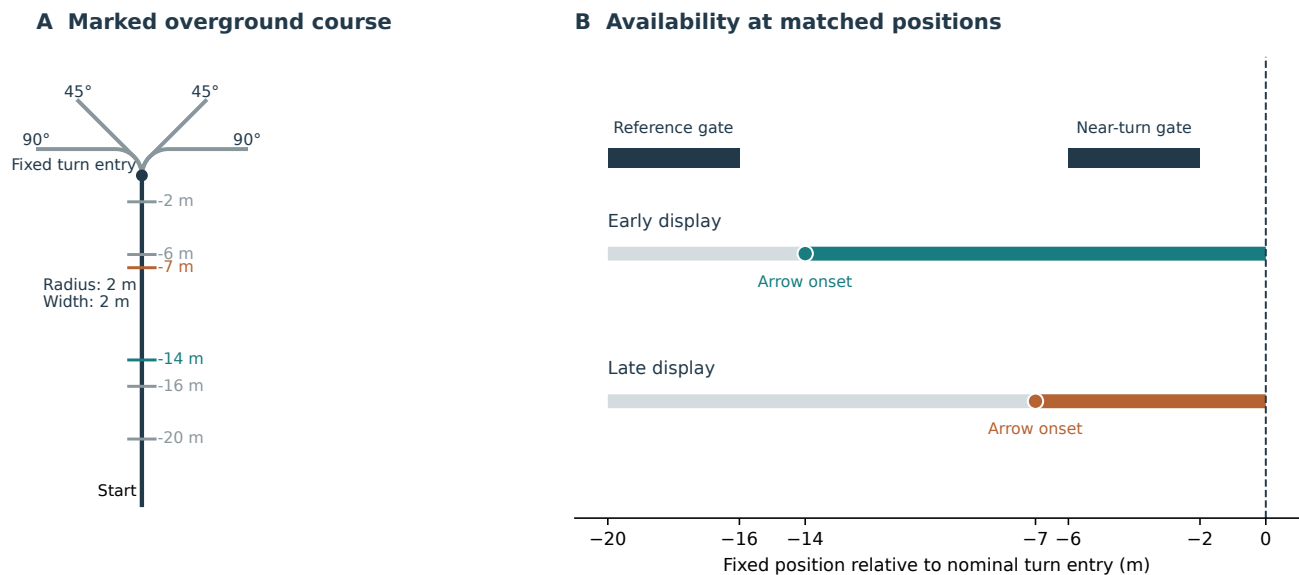


FIGURE 2. COURSE GEOMETRY AND ARROW ONSET. PANEL A LOCATES THE FIXED APPROACH, TURN ENTRY AND FOUR MARKED EXIT CENTRELINES; ROUTE WIDTHS ARE OMITTED. PANEL B PLACES THE REFERENCE GATE AT $[-20, -16]$ M, THE NEAR-TURN GATE AT $[-6, -2]$ M AND ARROW ONSETS AT -14 AND -7 M. EACH TIMING-ANGLE COMBINATION OCCURS WITH THE BRANCH UNKNOWN AND KNOWN BEFORE DEPARTURE.

Eight familiarization trials, one per cell, precede the randomized sequence and do not enter the analysis. The 48 trials occupy two sessions of 24 on the same day, separated by at least 15 min. A seated break of at least 2 min follows each block, with additional rest on request. The assessor gives no speed feedback. Session, block, within-block order, previous timing and participant-rated course familiarity are retained.

ELIGIBILITY AND SAFETY

The first implementation targets independently walking adults aged 18–45 years who understand the instructions and pass the arrow test. Corrected vision is permitted. Exclusions are lower-limb pain affecting walking, lower-limb injury or surgery within six months that limits walking, diagnosed neurological or vestibular disease affecting mobility, use of a walking aid, and inability to complete familiarization comfortably. Eligibility confines inference to this population.

The floor is dry, level and non-slip, without pedestrian traffic. An observer stands outside the route and stops a trial for a near fall, acute pain, dizziness or participant request. There is no imposed walking-speed target. The termination reason is recorded; continuation requires participant agreement. An observed movement-related termination can meet the noncompletion definition if consent permits retention. Equipment cancellation and withdrawal remain separate. Institutional ethical approval and written consent following explanation of procedures, risks and withdrawal rights are required before recruitment.

MOTION RECORDING AND OUTCOME DEFINITIONS

ACQUISITION AND CALIBRATION

A calibrated optical system samples pelvis, thorax and head rigid-body clusters at no less than 120 Hz. Each cluster contains at least three noncollinear markers. A neutral standing pose registers anatomical segment axes to the course frame. A photodiode samples actual arrow onset at 1 kHz on a clock synchronized with motion capture. Trigger commands, photodiode transitions and tracked positions are retained as separate records.

Calibration acceptance requires horizontal position root-mean-square error no greater than 10 mm over the approach and turning area, absolute yaw error no greater than 2° for known rotations, and interdevice clock disagreement no greater than 5 ms. Actual arrow onset must follow its command within 50 ms and occur within 0.10 m of the intended plane. At least twenty automated trigger passages covering 0.4–2.0 m/s precede each session. Their onset positions and delays are tabulated. Crossing-time accuracy and differentiated kinematics require independent checks in addition to position calibration. An alternative optical or wearable system must pass equivalent device-specific checks (Mason et al., 2022).

Crossing timestamps use unfiltered approach position and linear interpolation between adjacent samples. Confirmation requires position at least 20 mm beyond the plane for three consecutive samples; the timestamp remains the interpolated

first crossing. Returning across the plane does not reset the clock. A recording interruption longer than 50 ms within 0.25 m of a gate plane makes the crossing technically unavailable unless an independent synchronized optical record resolves it. Away from those planes, interruptions up to 50 ms may be interpolated for orientation and trajectory derivatives. Interpolation cannot erase a stop or supply an unresolved gate timestamp.

Continuous position and orientation components use a fourth-order, zero-phase Butterworth low-pass filter at 6 Hz. Gate-time outcomes use the unfiltered crossings. Derivative outcomes undergo sensitivity checks at 4 and 8 Hz. The photodiode signal does not use the motion filter. Installation records must identify manufacturer, model, firmware, acquisition software and measured calibration performance; the acceptance limits above do not assert achieved device accuracy.

PROGRESS, INTERRUPTIONS AND ROUTE ERRORS

The primary outcome is Q in Equation 7. Supporting quantities are completed-gate M , completion frequency, near-gate duration and reference speed. Total approach time runs from $s = -16$ m to the first valid passage through the prescribed turn-entry plane. Failure to reach that plane within 90 s yields a noncompletion event and a right-censored duration, rather than a completed 90 s traversal. A restricted-mean duration at 90 s is exploratory. This longer interval distinguishes local slowing from redistribution of preparation along the approach.

A stop begins when filtered horizontal pelvis speed is at most 0.05 m/s for at least 0.5 s. It ends after speed exceeds 0.05 m/s continuously for 0.2 s. Duration retains the original sample resolution; location is the median approach coordinate during the event. Gate time includes all elapsed time, even when slowing does not meet these stop thresholds. Reverse progress is a decrease of at least 0.10 m in approach coordinate after entry, and its duration remains inside T_g .

A route error is passage at least 3 m along an exit centreline other than the instructed branch, verified by synchronized video. A wrong exit after near-gate completion retains the measured Q . Lateral departure, hesitation and additional steps receive separate annotations. Assessment video masks the display and mutes audio to conceal timing and knowledge instructions. A second masked assessor resolves disagreements. Categorical agreement is quantified independently of the treatment comparison.

HEAD–THORAX ORIENTATION AND TURN EXECUTION

Absolute circular head–thorax yaw separation is

$$H(t) = \left| \text{atan2} \left\{ \sin(\psi_h(t) - \psi_t(t)), \cos(\psi_h(t) - \psi_t(t)) \right\} \right|. \quad (9)$$

Values are converted from radians to degrees. The prespecified summary is the time-weighted mean over near-gate traversal. The spatial profile from $s = -14$ to -2 m and orientation relative to measured arrow onset are exploratory. Left and right signed profiles share a reflected convention; absolute separation is unchanged. The measure does not identify fixation or recognition time.

Trunk turn onset is the first yaw-rate excursion beyond $10^\circ/\text{s}$ lasting at least 0.2 s and followed by at least 10° of sustained net heading change in the instructed direction. Its fixed approach coordinate is retained even if onset precedes $s = 0$. Peak yaw rate, turn duration, exit-heading error and progress speed through the prescribed arc are recorded. Planar trajectory curvature is

$$\kappa(t) = \frac{|\dot{x}\ddot{y} - \dot{y}\ddot{x}|}{(\dot{x}^2 + \dot{y}^2)^{3/2}}, \quad (10)$$

computed only while horizontal speed is at least 0.20 m/s. The uncomputed duration accompanies curvature summaries. Stops still contribute to gate time. At equal nominal radius, turn duration and integrated heading change provide angle-related mechanical checks; higher peak curvature is not a required consequence of the 90° turn.

TABLE 2. TRIAL CLASSIFICATION AND ANALYSIS RULES. EACH ASSIGNED TRIAL RETAINS ITS BEHAVIORAL, TECHNICAL OR CONSENT STATUS.

Observation	Primary handling	Additional record
Completed near gate, with pauses or reversals	Calculate $Q = M$ from complete elapsed time.	Gate times, stops, reversals and path deviations.
Wrong exit after near-gate completion	Retain measured Q under assigned timing.	Route error and exit heading.
Observed nonentry or noncompletion at the time limits	Assign the prespecified penalty $Q = 1$.	Failure type, deadline, last position and duration.
Unresolved crossing or failed motion recording	Leave Q technically missing.	Device reason, assigned cell and missingness sensitivity.
Arrow fails to appear at assigned timing	Retain assignment when Q is measured; flag delivery failure.	Actual onset and delivery-adherent comparison.
Consent withdrawal	Apply the participant's retention or deletion decision.	Withdrawal count and permitted earlier trials.

TREATMENT CONTRASTS AND STATISTICAL ANALYSIS

PRIMARY AND SECONDARY CONTRASTS

Let $\mu_{t,a,k}$ denote mean Q under timing t , turn angle a and knowledge condition k , with equal weights for left and right directions. The primary estimand is

$$\theta = \frac{1}{2} \sum_{a \in \{45,90\}} (\mu_{\text{late},a,\text{unknown}} - \mu_{\text{early},a,\text{unknown}}). \quad (11)$$

A positive θ denotes greater local suppression, more noncompletion, or both under later access when the branch is initially unknown. The assignment comparison retains wrong exits and display-delivery deviations. A delivery-adherent comparison is secondary.

The timing-by-knowledge contrast is

$$\eta = \frac{1}{2} \sum_{a \in \{45,90\}} [(\mu_{\text{late},a,\text{unknown}} - \mu_{\text{early},a,\text{unknown}}) - (\mu_{\text{late},a,\text{known}} - \mu_{\text{early},a,\text{known}})]. \quad (12)$$

Positive values of both θ and η , with successful recognition and comparable pre-onset speed, would indicate that advance branch knowledge changes the timing effect. They would not identify reading, attention or motor anticipation as its sole cause. Timing and knowledge are assigned factors; trial is the unit of assignment, and participant is the independent unit for generalization.

MIXED MODEL AND INTERVAL ESTIMATION

The confirmatory model is

$$Q_{ir} = \beta_0 + f(T_{ir}, A_{ir}, K_{ir}) + \gamma^T \mathbf{Z}_{ir} + b_{0i} + b_{Ti} T_{ir} + \epsilon_{ir}, \quad (13)$$

with binary timing, angle and knowledge factors. The function f includes three main effects, three two-factor interactions and the three-factor interaction. The adjustment vector $\mathbf{Z} = (D, B, P, F, S, O)$ contains direction, centred block number, previous late-timing assignment, a first-trial indicator, session and centred within-block position. Previous timing is zero on the first trial, with F marking the absent predecessor. Participant intercept and timing slope initially have an unstructured covariance, and residuals are initially conditionally independent. Factor coding and marginal weights are fixed before enrollment. Equation 11, rather than a coefficient restricted to one reference cell, defines the primary contrast.

Variance components use restricted maximum likelihood. Contrast intervals and tests use the Kenward–Roger small-sample adjustment. A singular or nonconvergent correlated random-effects fit is retried after covariate rescaling, then with an uncorrelated intercept and slope, then with an intercept only. The selected step, variance estimates and convergence warnings accompany the analysis. A robustness interval for θ uses 10,000 participant-cluster bootstrap draws, retaining every participant's trial set. Distributions of Q , completion penalties and participant contrasts are inspected rather than assuming Gaussian behavior in advance.

The primary test is two-sided at $\alpha = 0.05$, with a 95% confidence interval. One Holm-adjusted family contains three secondary tests: η , timing-by-angle in unknown-route trials, and timing for mean near-gate H . Route errors and non-completion receive cell proportions, participant-cluster intervals and supporting logistic mixed-model contrasts. Absent events or separation can prevent estimation; in that case, counts and proportions replace an unidentified finite logistic contrast. Exploratory speed profiles use participant-cluster simultaneous maximum-deviation bands over $[-14, -2]$ m, without individual-bin significance tests.

TECHNICAL LOSS AND SENSITIVITY ANALYSES

Every assigned cell retains the number and reason for technically missing outcomes. The mixed model assumes missingness is conditionally independent of an unobserved score after accounting for its included variables. Randomization alone does not establish that assumption. A sensitivity analysis uses fifty imputations conditional on timing, angle, knowledge, direction, order, participant, reference speed and available stop or video annotations. Further pattern-mixture analyses shift technically missing scores by ± 0.05 and ± 0.10 , separately by timing, to examine systematically higher or lower unobserved suppression. These shifts are prespecified analysis constants. Withdrawn measurements are not reconstructed.

Observed behavioral noncompletion retains its penalty. Additional analyses use entry/traversal deadline pairs of (35,20) and (55,40) s and penalties of 0.9 and 1.1. These define alternative scores rather than alternative measured speeds.

Completed-trial log speed ratios remain descriptive because selecting completion can select on a cue response. Modeling absolute near-gate time with reference time checks dependence on ratio normalization. Angle- and direction-specific timing contrasts accompany the pooled primary estimate.

Absolute reference speed provides a pre-onset comparison for the upcoming timing assignment. Normalizing a gate by itself yields one identically and cannot check equality between assignments. Reference-speed comparisons are made within knowledge condition with block and previous timing retained. Turn onset before the near gate is included and tabulated by cell. If cue timing relocates pauses without changing total approach duration or errors, the interpretation is a shift in the position of preparation.

PRECISION, SAMPLE SIZE AND FEASIBILITY

MEASUREMENT CHECKS AND TIMESTAMP SENSITIVITY

Table 1 and Figure 1 evaluate the pause equations directly. Before human testing, processing checks require constant-speed motion to return $M = 0$, doubled near-gate duration to return $M = 0.5$, and an inserted pause to increase T_g by its full duration. Reversals must retain all time from first entry to valid exit. Changing spatial-bin width must leave Equation 1 unchanged. A missing exit receives a noncompletion penalty only when the record establishes behavioral failure; an unresolved timestamp remains technical loss.

For small gate-time errors,

$$\delta M \simeq -\frac{\delta T_{\text{ref}}}{T_{\text{near}}} + \frac{T_{\text{ref}}}{T_{\text{near}}^2} \delta T_{\text{near}}. \quad (14)$$

With equal 3.333 s traversals and each gate-time error bounded by 0.025 s, opposing error signs give a first-order error magnitude of approximately 0.015. This is an error-propagation calculation. Achieved uncertainty depends on measured crossing errors, their covariance and the onset-delay distribution. The gate-time system therefore needs independent calibration before resolving a small mean contrast.

RECRUITMENT CALCULATION AND PROGRESSION CRITERIA

The initial recruitment target is 80 participants, aiming for at least 67 with sufficiently measured repeated trials. A simple paired calculation uses each participant's balanced unknown-route timing contrast. Define d_z as its mean divided by the between-participant standard deviation. For $d_z = 0.35$, a two-sided paired t test at $\alpha = 0.05$ and 80% power requires 67 participants. A noncentral- t calculation gives approximately 0.87 power at $n = 80$. Effects of $d_z = 0.25$ and 0.45 require 128 and 41 participants, respectively. These counts depend on assumed effect and variation; they are not estimates from recruited walkers.

A mean Q difference of 0.04 is the planning target. Among completed trials, it represents four percentage points of relative progress suppression; it has no established clinical importance. Twelve independently recruited feasibility participants precede confirmatory enrollment and are analyzed separately. Their records assess trigger delivery, technical loss, arrow recognition, completion, gate reliability, session tolerability and participant-contrast variance. Simulation of Equation 13 then fixes confirmatory sample size using the balanced schedule, measured feasibility variance, technical loss and alternative completion rates. Simulations also examine at least 25% greater participant-contrast variability. The target of 80 and the paired calculation do not establish power for η or interaction tests. The final count and simulation assumptions are registered before confirmatory recruitment.

Known-route repeated gate times and orientation outcomes provide within-participant standard errors of measurement and repeatability intervals. An intraclass coefficient alone does not establish agreement. Optical and independently synchronized video gate times are compared using bias and limits of agreement. Arrow accuracy and onset positions are tabulated by distance and session. Technical loss above 10%, walking recognition below 95%, or repeated safety-related termination prevents confirmatory progression until the delivery or measurement problem is resolved. These percentages are decision rules for feasibility testing.

INTERPRETATION AND SCOPE

A cue-timing contrast concerns assignment to this display on this course. Information acquisition, the visual onset event, motor preparation and path changes can each contribute. The known-route condition asks whether advance branch knowledge modifies the contrast while retaining the arrow event. Similar timing effects with known and unknown branches would weaken an explanation dependent on newly acquired branch information. A narrow interval excluding the

0.04 planning target would limit the size of the local effect under the tested conditions. Recognition failures or pre-onset speed differences require examination of delivery, allocation, carryover and measurement error.

Local speed is interpreted alongside route errors, stops, total approach duration and turn execution. Visual dual tasks can affect gait variables differently (Kimura and van Deursen, 2020), so faster approach progress is not automatically safer. The protocol records no physiological endpoint and provides no direct fall-risk or workload assessment. A local timing effect can coexist with an unchanged total duration, or with fewer errors despite more slowing.

Sign-layout and signage experiments connect environmental information to navigation behavior (Li et al., 2022; Yu et al., 2023). Transfer from this unobstructed course to public buildings requires attention to occlusion, crowds, multilingual instructions and changing light. The first eligibility criteria exclude walking-aid users and several mobility disorders; clinical use requires independent testing with accessible geometry and cue modalities. Anticipatory body signals have also been investigated for robotic mobility assistance (Farkhatdinov et al., 2017). Head-thorax yaw in this protocol does not by itself establish an intention detector.

Implementation records must separate scheduled, reference-ineligible, randomized, delivered, behaviorally incomplete, technically missing and withdrawn trials. Results of a future human study must include achieved calibration, cell-specific recognition, both components of Q , treatment contrasts and prespecified sensitivities. Raw timestamps, allocation records, event definitions, processing code and a de-identified dictionary accompany those measurements where consent and institutional policy permit. These requirements specify what must be collected; no such participant records currently exist.

CONCLUSION

Complete elapsed gate time preserves interruption in a fixed-distance progress measure. For a single interrupted bin, an arithmetic spatial average has a ceiling of $1/N$, whereas complete-gate suppression approaches one as pause duration increases. The overground protocol assigns arrow onset at -14 or -7 m while retaining fixed gates and nominal turn geometry. Advance branch knowledge, approach duration, errors and segment orientation support separate comparisons. The equations establish pause sensitivity; human feasibility, repeatability and cue-timing effects require prospective testing.

DECLARATIONS

CONFLICT OF INTEREST

The author declares 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.

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