

PASSING BEFORE POSSESSION LOSS: OPTIMAL INITIATION OF A DEVELOPING RECEIVING OPPORTUNITY

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ABSTRACT

Receiver movement can increase the value of a pass during the interval in which a ball carrier remains exposed to dispossession. This study determines the initiation time of one specified pass under a fixed waiting policy. Expected utility includes the outcome after initiation, possession loss before initiation and an additional charge for time spent waiting. Differentiation gives the condition $r'(t) > \lambda(t)[r(t) + L(t)] + c(t)$ for a locally beneficial delay, where r is conditional pass value, λ is the loss hazard, L is the magnitude of the loss payoff and c is the waiting-cost rate. Exponential development of pass value and constant hazard yield an exact optimum within a finite initiation interval. With initial value 0.30, development amplitude 0.60, development rate 0.90 s^{-1} , loss payoff -0.75 , time charge 0.04 utility units per second and a 3-s limit, hazards of 0.08, 0.35 and 0.70 s^{-1} produce optimal delays of 1.366, 0.216 and 0 s. The largest positive delay occurs at a unique development rate: increasing that rate first lengthens and then shortens optimal waiting. The three maximum delays are 1.440, 0.413 and 0.215 s. Numerical optimisation and integration agree with the closed-form calculations to within 3.34×10^{-16} utility units across 10,062 parameter combinations. These are calculated properties of the specified functions, without athlete measurements. Their application to passing depends on measuring movement initiation, retaining premature losses and valuing every timing strategy over the same outcome horizon.

Keywords: pass initiation; receiving opportunity; possession loss; tactical timing; interpersonal coordination; optimal stopping

INTRODUCTION

The interval preceding a pass has two opposing consequences. Receiver–marker separation can improve the receiving opportunity, while continued ball control exposes the carrier to dispossession. A shorter interval reduces that exposure but may precede the receiver's useful movement. The timing question is therefore the expected consequence of initiating a particular pass at time t , including possessions lost before that time.

Basketball decision studies establish the value of comparing an immediate action with continued possession. Skinner's shot-selection analysis includes turnover risk and the number of remaining opportunities (Skinner, 2012). Goldman and Rao examine shooting thresholds relative to continuation value (Goldman and Rao, 2017). Sandholtz and Bornn represent changing shooting decisions through non-stationary Markov decision processes (Sandholtz and Bornn, 2020). The present decision has one continuously developing candidate action: the receiver and passing technique remain fixed, and the carrier selects an initiation delay in advance. This restriction permits a closed-form timing calculation rather than a sequence of choices among newly encountered actions.

The kinesiology of this interval concerns relations among moving players. Ecological dynamics treats performance as dependent on interactions between athletes and their environment (Vilar et al., 2012). Interpersonal distance influences

coordination in rugby (Passos et al., 2011), and futsal passing research connects passing actions with interactions among carriers, receivers and defenders (Travassos et al., 2012). Soccer task constraints also affect perceptual-cognitive activity (Roca et al., 2013). These findings support distinguishing an executable receiving opportunity from an unoccupied region of the playing area. They do not supply the loss hazard or the pass-value function used below.

Outcome valuation provides the second requirement. Basketball possession models quantify the consequences of an evolving possession (Cervone et al., 2016). Football analyses evaluate passing risk and reward (Power et al., 2017), the value of player actions (Decroos et al., 2019) and pass difficulty (Anzer and Bauer, 2022). A timing comparison additionally needs the losses occurring before an attempted pass. The following analysis therefore defines the waiting behaviour, pass, terminal payoff and initiation interval together, then derives the optimum and its response to changes in opportunity-development rate.

DEFINITION OF THE TIMING COMPARISON

WAITING POLICY, PASS AND OBSERVABLE INITIATION

Time zero is an instant of controlled possession at which the designated receiver and passing technique are available. The waiting policy π specifies what the carrier does before passing, for example shielding the ball within a defined area. The candidate action A specifies the receiver and execution rule. Strategy g_t follows π until time t and initiates A if possession remains controlled. All delays start from the same eligible possession population and use the same policy before initiation.

Let T^π denote the premature-loss time under continued waiting. Premature loss terminates the focal possession phase. Initiation is the observable onset of the prescribed passing movement, whereas release is the subsequent separation of the ball from the carrier. The decision variable is initiation time; an unobserved intention to pass cannot substitute for it. Superscripts are omitted below when the policy is unambiguous.

The selected delay remains fixed after time zero. A carrier who changes the timing after observing a defender or switches receivers follows a different strategy. The equations here compare scalar delays for A under π ; they do not choose a receiver, optimise shielding behaviour or evaluate a state-dependent stopping rule.

PAYOFF SCALE AND DURATION CONSTRAINT

Let W be a common outcome horizon measured from time zero, and let Y^{g_t} be terminal utility under strategy g_t . An outcome reached before W remains an absorbing state until that horizon. Conditional pass value is

$$r(t) = \mathbb{E}[Y^{g_t} \mid T^\pi > t]. \quad (1)$$

Thus $r(t)$ includes inaccurate execution, interception after initiation and the receiving outcome. A loss at time $u < t$ has conditional payoff $-L(u)$, with $L(u) \geq 0$. Pass outcomes and premature losses use the same utility scale and horizon. Execution failure already counted in $r(t)$ is not charged again through L .

The calculation in Section uses +1 for controlled target reception, -0.75 for defender control before reception and 0 for neutral termination. Under the binary restriction to reception or defender control, pass success probability $p(t)$ satisfies

$$r(t) = 1.75p(t) - 0.75, \quad p(t) = \frac{r(t) + 0.75}{1.75}. \quad (2)$$

The values $r = 0.30$ and $r = 0.90$ correspond to probabilities 0.6000 and 0.9429 on this scale. If neutral terminations have positive probability, r alone does not determine reception probability.

A non-negative rate $c(u)$ charges additional utility for time spent waiting while possession survives. It is separate from the terminal payoff. When Y already accounts for the full consequence of consuming attacking time, $c = 0$ avoids counting that consequence twice. The calculation uses $c = 0.04$ utility units per second.

Let D be the completion deadline and d a constant execution duration. When $D \geq d$, the last feasible initiation time is $H = D - d$. If $D < d$, the pass is infeasible even at time zero. For duration $d(t)$ dependent on initiation time, the admissible set is

$$\mathcal{F} = \{t \geq 0 : t + d(t) \leq D\}. \quad (3)$$

The exact optimum below assumes $\mathcal{F} = [0, H]$. A disconnected admissible set requires comparison of the stationary points and boundaries within that set.

TABLE 1. DEFINITIONS AND DIMENSIONS OF THE TIMING VARIABLES.

Symbol	Definition	Unit
t, H	Initiation delay and last feasible initiation time	s
$S(t)$	Probability of possession surviving until t under π	dimensionless
$\lambda(t)$	Conditional hazard of premature possession loss	s^{-1}
$r(t)$	Conditional terminal utility after pass initiation	utility
$L(t)$	Magnitude of the conditional premature-loss payoff	utility
$c(t)$	Additional charge per second of surviving waiting	utility/s
r_0, a	Initial pass value and its saturation amplitude	utility
k	Rate of exponential pass-value development	s^{-1}

NUMERICAL CALCULATION

The analysis uses specified utility functions and parameter values; no athlete recordings or match observations enter the calculations.

The first calculation set contains 102 hazard values: zero and 101 equally spaced values from 0.02 to 1.00 s^{-1} . Crossing them with 51 equally spaced loss magnitudes from 0 to 1.50 gives 5,202 combinations, with $r_0 = 0.30$, $a = 0.60$, $k = 0.90 \text{ s}^{-1}$, $c = 0.04$ and $H = 3 \text{ s}$. The second set is the Cartesian product of

$$\begin{aligned}
 \lambda &\in \{0, 10^{-8}, 0.08, 0.35, 0.70, 1.00\} \text{ s}^{-1}, \\
 L &\in \{0, 0.75, 1.50\}, \\
 r_0 &\in \{0, 0.30\}, \\
 a &\in \{0, 0.05, 0.60\}, \\
 k &\in \{0.20, 0.90, 3.00\} \text{ s}^{-1}, \\
 c &\in \{0, 0.04, 0.80\}, \\
 H &\in \{0, 0.05, 0.25, 3.00, 8.00\} \text{ s}.
 \end{aligned}$$

The loss, initial value and amplitude are in utility units; the charge rate is in utility units per second. This product gives 4,860 combinations, including zero hazard, zero value growth and zero initiation interval. For each of the 10,062 combinations, bounded scalar optimisation is compared with both endpoints. Adaptive quadrature evaluates the combined loss and waiting-charge integral independently of the closed-form expression.

DERIVATION OF OPTIMAL INITIATION

POSSESSION SURVIVAL AND THE VALUE OF ANOTHER INSTANT

Assume an absolutely continuous loss-time distribution with $S(0) = 1$, a finite cumulative hazard and differentiable conditional pass value. Possession survival is

$$S(t) = \exp\left[-\int_0^t \lambda(u) du\right]. \quad (4)$$

The loss-time density is $S(u)\lambda(u)$. A surviving possession contributes $r(t)$ after initiation; a possession lost at $u < t$ contributes $-L(u)$. The waiting charge accumulates until $\min(T^\pi, t)$. Expected utility is consequently

$$J(t) = S(t)r(t) - \int_0^t S(u)\lambda(u)L(u) du - \int_0^t S(u)c(u) du. \quad (5)$$

Using $S'(t) = -\lambda(t)S(t)$ gives

$$J'(t) = S(t)\{r'(t) - \lambda(t)[r(t) + L(t)] - c(t)\}. \quad (6)$$

Since $S(t) > 0$ at finite cumulative hazard, an infinitesimal additional delay increases utility exactly when

$$r'(t) > \lambda(t)[r(t) + L(t)] + c(t). \quad (7)$$

The three terms are rates of utility change. Growth in conditional pass value must exceed both the value exposed to loss and the additional time charge. The exposed value is $r(t) + L(t)$ because premature loss forfeits the surviving pass outcome and incurs the adverse loss payoff.

Eq. (7) is local. A pass-value function that rises, falls and rises again can produce several stationary points, all of which must be compared with feasible boundaries. Furthermore, $r'(t)$ differentiates a survival-conditioned value across strategies. It does not isolate the effect of delaying the same athlete in an otherwise identical possession.

EXPONENTIAL VALUE DEVELOPMENT AND A FINITE INITIATION INTERVAL

For one improving receiving opportunity, let

$$r(t) = r_0 + a(1 - e^{-kt}), \quad r_0 \geq 0, \quad a > 0, \quad k > 0. \quad (8)$$

The value rises from r_0 towards $r_0 + a$, with initial slope ak and time constant $1/k$. For constant $\lambda > 0$, $L \geq 0$ and $c \geq 0$, integration of Eq. (5) gives

$$J(t) = e^{-\lambda t} [r_0 + a(1 - e^{-kt})] - \left(L + \frac{c}{\lambda}\right) (1 - e^{-\lambda t}). \quad (9)$$

Define $Q = \lambda(r_0 + a + L) + c$. Then

$$J'(t) = e^{-\lambda t} [a(k + \lambda)e^{-kt} - Q]. \quad (10)$$

The bracket decreases strictly with t , so its positive zero is the only interior maximum. For $0 \leq t \leq H$, the optimum is

$$t^* = \min \left\{ H, \max \left[0, \frac{1}{k} \log \left(\frac{a(k + \lambda)}{Q} \right) \right] \right\}. \quad (11)$$

For $H > 0$, immediate initiation occurs if and only if

$$ak \leq \lambda(r_0 + L) + c. \quad (12)$$

If $ak > c$ and $r_0 + L > 0$, its hazard boundary is

$$\lambda_{\text{boundary}} = \frac{ak - c}{r_0 + L}. \quad (13)$$

The deadline determines the optimum when the logarithmic time in Eq. (11) is at least H , equivalently when $a(k + \lambda)e^{-kH} \geq Q$.

At zero hazard, $J(t) = r(t) - ct$. For $c > 0$, the optimum is $k^{-1} \log(ak/c)$ clipped to $[0, H]$. For $c = 0$ and $a > 0$, value increases throughout the interval and $t^* = H$. For $a = 0$, the non-negative initial value, loss magnitude and time charge make immediate initiation optimal, with ties when utility is constant. The numerical calculation selects zero in those ties. When $H = 0$ and the pass is feasible, zero is the sole admissible delay.

EFFECT OF LOSS EXPOSURE AND TIME CHARGE

For an interior optimum with $\lambda > 0$, differentiating Eq. (11) yields

$$\frac{\partial t^*}{\partial L} = -\frac{\lambda}{kQ}, \quad \frac{\partial t^*}{\partial c} = -\frac{1}{kQ}, \quad \frac{\partial t^*}{\partial \lambda} = \frac{c - k(r_0 + a + L)}{k(k + \lambda)Q}. \quad (14)$$

Each derivative is negative. A positive delay requires $c < ak$, while $k(r_0 + a + L) \geq ak$; hence the numerator of the hazard derivative is negative as well. Greater loss magnitude, hazard or additional time charge therefore shortens the interior delay. At zero and at H , clipping creates constant intervals or one-sided changes.

A UNIQUE PEAK AS DEVELOPMENT BECOMES FASTER

Holding r_0, a, L, c and λ fixed, let $\tilde{t}$ be the unconstrained stationary time. Its derivative with respect to k is

$$\frac{d\tilde{t}}{dk} = \frac{k/(k + \lambda) - \log[a(k + \lambda)/Q]}{k^2}. \quad (15)$$

Suppose $\lambda > 0$ and $\lambda(r_0 + L) + c > 0$. The threshold for positive delay is

$$k_0 = \frac{\lambda(r_0 + L) + c}{a}. \quad (16)$$

For $k \leq k_0$, the constrained optimum is zero. At k_0 , the logarithm in Eq. (15) is zero. For the numerator

$$h(k) = \frac{k}{k + \lambda} - \log \left[\frac{a(k + \lambda)}{Q} \right],$$

we therefore have $h(k_0) > 0$, whereas

$$h'(k) = -\frac{k}{(k + \lambda)^2} < 0, \quad \lim_{k \rightarrow \infty} h(k) = -\infty. \quad (17)$$

Continuity and strict decrease imply exactly one root $k_{\text{peak}} > k_0$. The positive stationary delay increases up to this root and decreases after it. At the root,

$$\log \left[\frac{a(k_{\text{peak}} + \lambda)}{Q} \right] = \frac{k_{\text{peak}}}{k_{\text{peak}} + \lambda}, \quad \tilde{t}(k_{\text{peak}}) = \frac{1}{k_{\text{peak}} + \lambda}. \quad (18)$$

The initiation limit can replace the peak with a plateau at H . The exception $r_0 = L = c = 0$ has $k_0 = 0$ and positive delay for every $k > 0$; that delay decreases throughout. Thus the increase followed by decrease requires a positive initial loss burden or time charge.

CALCULATED TIMING BOUNDARIES AND UTILITIES

THREE LOSS HAZARDS AT A FIXED DEVELOPMENT RATE

Set $r_0 = 0.30$, $a = 0.60$, $k = 0.90 \text{ s}^{-1}$, $L = 0.75$, $c = 0.04$ utility units per second and $H = 3 \text{ s}$. Initial value growth is $ak = 0.54$ utility units per second, and the value-development time constant is $1/k = 1.111 \text{ s}$. Eq. (13) gives

$$\lambda_{\text{boundary}} = \frac{0.54 - 0.04}{0.30 + 0.75} = 0.476190 \text{ s}^{-1}.$$

At or above this hazard, immediate initiation maximises utility. Below it, the optimum is positive unless the feasible interval has zero length.

TABLE 2. OPTIMAL DELAY, POSSESSION SURVIVAL AND UTILITY FOR $k = 0.90 \text{ s}^{-1}$. ALL ROWS USE $r_0 = 0.30$, $a = 0.60$, $L = 0.75$, $c = 0.04$ AND $H = 3 \text{ s}$.

$\lambda \text{ (s}^{-1}\text{)}$	$t^* \text{ (s)}$	$S(t^*)$	$J(t^*)$	$J(0.50 \text{ s})$
0.08	1.366	0.896	0.5201	0.4481
0.35	0.216	0.927	0.3135	0.2956
0.70	0.000	1.000	0.3000	0.1263

Immediate initiation has utility $J(0) = 0.3000$ in all three cases. At $\lambda = 0.08 \text{ s}^{-1}$, the optimum adds 0.2201 utility units, with survival 0.8965. At $\lambda = 0.35 \text{ s}^{-1}$, it adds only 0.0135 units, with survival 0.9272. This higher survival at the optimum arises from the much shorter selected delay; survival at any common positive delay still decreases as hazard increases. A 0.50-s delay at hazard 0.35 s^{-1} gives 0.2956 units, falling below immediate initiation despite the existence of a positive optimum. At 0.70 s^{-1} , the same half-second delay gives 0.1263 units, a reduction of 0.1737 units from immediate initiation.

DEVELOPMENT THRESHOLDS AND MAXIMUM WAITING TIMES

For the same r_0 , a , L , c and H , Table 3 varies k rather than fixing it at 0.90 s^{-1} . The onset k_0 comes from Eq. (16); the peak rate is the unique root in Eq. (18). All three peak delays are below 3 s, so the initiation limit does not clip these curves.

TABLE 3. DEVELOPMENT RATE REQUIRED FOR POSITIVE WAITING AND THE RATE YIELDING THE GREATEST OPTIMAL DELAY.

$\lambda \text{ (s}^{-1}\text{)}$	$k_0 \text{ (s}^{-1}\text{)}$	$k_{\text{peak}} \text{ (s}^{-1}\text{)}$	Maximum delay (s)
0.08	0.2067	0.6145	1.4400
0.35	0.6792	2.0710	0.4131
0.70	1.2917	3.9586	0.2147

At hazard 0.08 s^{-1} , the fixed rate 0.90 lies beyond the peak rate 0.6145 . At 0.35 s^{-1} , it lies between the onset 0.6792 and peak 2.0710 . At 0.70 s^{-1} , it lies below the onset 1.2917 , explaining the zero-delay entry in Table 2. The ordering of these rates identifies whether increasing k lengthens waiting, shortens it or leaves immediate initiation optimal.

Across the 10,062 combinations, the largest absolute difference between closed-form optimal utility and endpoint-inclusive numerical maximisation was 3.330669×10^{-16} units. The largest difference between direct integration and the closed-form utility was 1.110223×10^{-16} units. These checks concern achieved utility: several initiation times can yield the same value when the objective is constant. Parameter combinations are deterministic calculations and do not form an athlete sample or a sampling distribution.

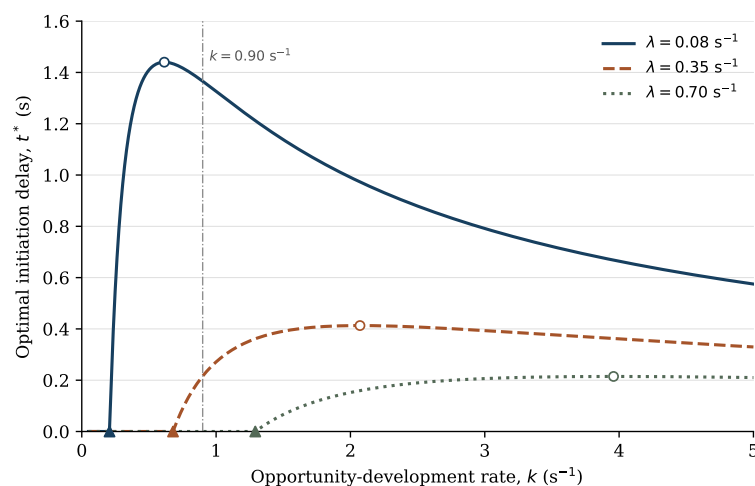


FIGURE 1. OPTIMAL INITIATION DELAY AS A FUNCTION OF EXPONENTIAL PASS-VALUE DEVELOPMENT RATE. CURVES USE $r_0 = 0.30$, $a = 0.60$, $L = 0.75$, $c = 0.04$ UTILITY UNITS PER SECOND AND $H = 3$ S. TRIANGLES LOCATE THE ZERO-TO-POSITIVE THRESHOLDS k_0 ; OPEN CIRCLES LOCATE THE UNIQUE DELAY MAXIMA. THE VERTICAL LINE AT $k = 0.90 \text{ s}^{-1}$ INTERSECTS THE THREE CURVES AT THE DELAYS IN TABLE 2.

MOVEMENT INTERPRETATION AND LIMITS OF APPLICATION

WHAT THE DEVELOPMENT RATE REPRESENTS

The parameter k describes the rate at which conditional pass value approaches its asymptote. Receiver speed alone does not determine it. Carrier-defender distance, receiver-marker separation, orientation, approach velocity and release-to-reception duration can all affect whether the intended receiver can obtain controlled possession. Spatial attacking threat changes with player and ball positions (Link et al., 2016); the existence of open space does not establish the attainability of a reception.

The rising part of Figure 1 begins when value growth first exceeds the initial exposure burden. A further increase in k then makes waiting worthwhile for longer. Beyond the peak, value approaches its asymptote sufficiently quickly that the carrier can obtain most of the improvement with a shorter interval. Hence faster development of the receiving opportunity has no single directional effect on the optimal delay. Movement training that changes separation also changes the interpretation if it alters the attainable value amplitude a , the initial value r_0 or the loss hazard at the same time.

The loss sensitivities in Eq. (14) likewise hold other quantities fixed. A shielding movement may reduce hazard while restricting pass execution, and an approach by a defender may increase hazard while opening a receiver elsewhere. Such changes require separate estimates of r and λ for each waiting policy. Substituting one changed parameter while ignoring the other would not evaluate that movement behaviour.

COMPLETE POSSESSIONS AND TIMING MEASUREMENT

An empirical timing comparison needs a common definition of eligibility, time zero, waiting policy, candidate pass and outcome horizon. These specifications are also central to causal comparisons of complete treatment strategies (Hernán and Robins, 2016). A possession lost before a planned initiation must remain part of the strategy's value. Restricting analysis to completed passes removes precisely the loss term that distinguishes immediate from delayed initiation.

Late surviving possessions can differ in carrier skill or defensive pressure from early losses. The conditional definition of $r(t)$ retains that distinction; an increase in $r(t)$ is not, by itself, proof that an additional delay improved the same carrier's pass. Strategy value $J(t)$ combines survivors and premature losses. Analyses intended to compare tactical instructions must therefore evaluate this complete value rather than reception success among the survivors alone.

Movement initiation and release need separate event times. The difference between them is execution duration, whereas the difference between a timing cue and initiation is response latency. Substituting cue time or release time for initiation changes the exposure interval in Eq. (5). A delay instruction with variable response latency evaluates a distribution of actual initiation times. It cannot be assigned the utility of a single exact time without accounting for that variation and its dependence on possession state.

WHEN THE CLOSED-FORM OPTIMUM CEASES TO APPLY

Exponential saturation requires pass value to increase monotonically towards $r_0 + a$. A receiver who first escapes a marker and then encounters a second defender can violate that requirement. Constant hazard requires exponential possession survival; defensive pressure that accelerates during shielding can violate it. Eq. (5) still accommodates time-varying functions, but Eq. (11) then requires replacement by direct maximisation of the corresponding utility.

Fouls, boundary exits and recoverable losses need their own event payoffs when they terminate waiting differently from defender control. The integral expression can include a sum of event-specific hazards and payoffs, with survival referring to the absence of all terminating events. A loss that has positive terminal utility also changes the sign restriction on L and can invalidate the monotone loss sensitivities. Non-negative loss magnitude is therefore an application assumption, not a statement about every possession-ending event.

Multiple receivers, opponent adaptation and information acquired while waiting create additional decisions. A switch in the highest-valued action can make the action-value envelope non-differentiable; switch points must then be compared with stationary points and boundaries. Sequential shot acceptance (Skinner, 2012; Goldman and Rao, 2017) and state-dependent decision processes (Sandholtz and Bornn, 2020) address decision structures that are absent from the fixed-delay calculation.

Passing tasks must preserve the athlete's interaction with moving opponents if their estimates are to represent that interaction (Pinder et al., 2011). Tactical context also exceeds counts of passes or possessions (Rein and Memmert, 2016). The numerical values in Tables 2 and 3 therefore establish timing relationships for the specified utility functions. They supply neither a universal passing instruction nor estimates of futsal, football or basketball performance.

CONCLUSION

For one designated pass under a fixed waiting policy, the utility of delay is the surviving pass value minus premature-loss payoff and accumulated time charge. With constant loss hazard and exponential pass-value development, the exact constrained optimum follows from a single decreasing derivative. The initial growth rate ak must exceed $\lambda(r_0 + L) + c$ for positive waiting. Development rate has a distinct effect: above its onset threshold, optimal delay rises to one peak and then falls. At $k = 0.90 \text{ s}^{-1}$, the specified utilities yield delays of 1.366, 0.216 and 0 s for hazards 0.08, 0.35 and 0.70 s^{-1} . Applying these timing relations to athletes requires complete possession outcomes and movement-initiation times under a common payoff horizon.

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.

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