# Signal Parity and Lane Integrity in Sex-Stratified Structural-Load Simulation

A non-extractive evidence-governance study of female sport lanes and managed-burden transparency

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## Abstract

**Background.** Women athletes and under-resourced communities are often caught between two failures: safety systems that under-measure their structural-load reality and monitoring systems that over-expose their bodily data to institutions. A credible safety framework must therefore preserve female-lane signal while preventing safety evidence from becoming a new surveillance asset.

**Objective.** This companion paper evaluates source-labeled female sport lanes from the LAKANA SSI simulation and interprets them through lane integrity, managed-burden transparency, and anti-extractive governance. It does not claim female-specific clinical validation, demographic subgroup validation, field effectiveness, or injury prevention.

**Methods.** The companion analyzed women's or female basketball where source-labeled, female soccer, and softball. Outcomes included missed-days movement, ACL-family proxy movement, modeled time-years, position-specific contrasts, managed-burden tradeoffs, Aalen-Johansen cumulative-incidence summaries, Fine-Gray subdistribution summaries, Markov pathway logic, female-stack MEBVB precision, and RET-BURD retained-time/burden classification. The analysis treated female-lane interpretation as a scoped companion to the whole-frame paper rather than as a pooled subgroup afterthought. Governance analysis examined whether public evidence could be reviewed through aggregate, pathway-level, claim-bounded artifacts rather than raw subject trajectories. Female-stack precision and public evidence discipline were interpreted through the Sovereign Structural Evidence Stack (SSES), LAKANA's post-run evidence-governance layer for source linkage, claim-boundary enforcement, and non-extractive public release.

**Results.** Weighted mean movement favored the SSI pathway in all three female lanes displayed in the evidence map: missed days moved from 169.16 to 91.37 in women's basketball, 158.29 to 89.98 in women's soccer, and 101.50 to 63.06 in softball; cumulative ACL-family proxy moved from 1.876 to 0.596, 1.754 to 0.568, and 1.121 to 0.117, respectively; modeled time-years moved from 0.194 to 0.449, 0.250 to 0.470, and 0.446 to 0.595. Female-stack MEBVB reported B=180 effective precision blocks and a simulator-internal interval of [2,280,391.93, 3,111,841.08] burden-delta units; RET-BURD classified 162 of 180 blocks as dominant favorable and 18 as managed-burden tradeoff. Female soccer field and goalkeeper rows showed different movement patterns, supporting position-specific interpretation. Softball pitcher-catcher results exposed the key cautionary tradeoff: favorable proxy movement can coexist with increased simulator-implied days missed in a high-load role.

**Interpretation.** The companion's contribution is not a claim that SSI improves women's sport outcomes in the real world. Its contribution is a public framework for preserving female-lane evidence, reporting managed-burden tradeoffs honestly, and designing safety review so that transparency does not become extraction.

**Keywords:** female athletics; women's soccer; softball; women's basketball; structural-load intelligence; lane integrity; managed burden; anti-extractive governance; athlete data rights; simulation.

## Reader navigation and package dependencies

This companion is part of a four-document public research suite. The main manuscript defines the whole-frame B=390 simulation claim and the retained-time, event-history, sensitivity, and public evidence-governance results. This companion is narrower: it interprets source-labeled women's or female basketball, female soccer, and softball lanes under B=180 female-stack scope and does not own the whole-frame claim. The engineering technical supplement defines the state-space mechanics, TSARO/NICOLE governance abstractions, formal public-safe results, model-family stack, and SSES evidence-governance layers. The concise evidence summary gives a short map of the suite for reviewers.

The companion should therefore be read as a scoped female-lane and anti-extractive governance paper, not as a second whole-frame results paper and not as demographic subgroup validation.

## 1. Introduction: the equity paradox in athlete safety

Female athletics and minority-protective governance cannot be treated as public-relations additions to athlete safety research. They are methodological requirements. A pooled system can look stable while erasing female-specific exposure, role, roster, recovery, and workload structure. At the same time, an over-instrumented system can collect intimate bodily signals from athletes and communities that have the least power to refuse institutional use.

This is the equity paradox: under-measurement can leave women athletes unprotected, while over-exposure can turn protection into surveillance. The solution is not to avoid measurement. The solution is to preserve lane-specific evidence while controlling custody, purpose, access, release, and public interpretation.

This companion interprets female-lane evidence from the LAKANA SSI simulation. It is paired with the whole-frame main paper but does not claim global whole-frame evidence. Its purpose is to show how female-lane simulation results should be read when both structural-load science and governance risk matter.

## 2. Scope and conceptual frame

The companion includes three source-labeled female sport domains: women's or female basketball where the available evidence label it that way, female soccer, and softball. The companion separates these lanes because female sport is not a generic subgroup. Soccer field players, soccer goalkeepers, softball field players, softball pitcher-catcher roles, and basketball lanes carry different exposure structures and different validation needs.

The companion uses three interpretive principles.

First, **lane integrity**: source-labeled female lanes should not be collapsed into a pooled athlete category when the simulation preserves sport and position structure.

Second, **managed-burden transparency**: retained time and favorable proxy movement must be interpreted with restriction and days-missed behavior rather than converted into a simple success story.

Third, **anti-extractive governance**: public evidence review should use aggregate, pathway-level, claim-bounded artifacts rather than unrestricted raw subject trajectories.

Figure 1 defines the companion scope and shows its separation from the whole-frame main paper.

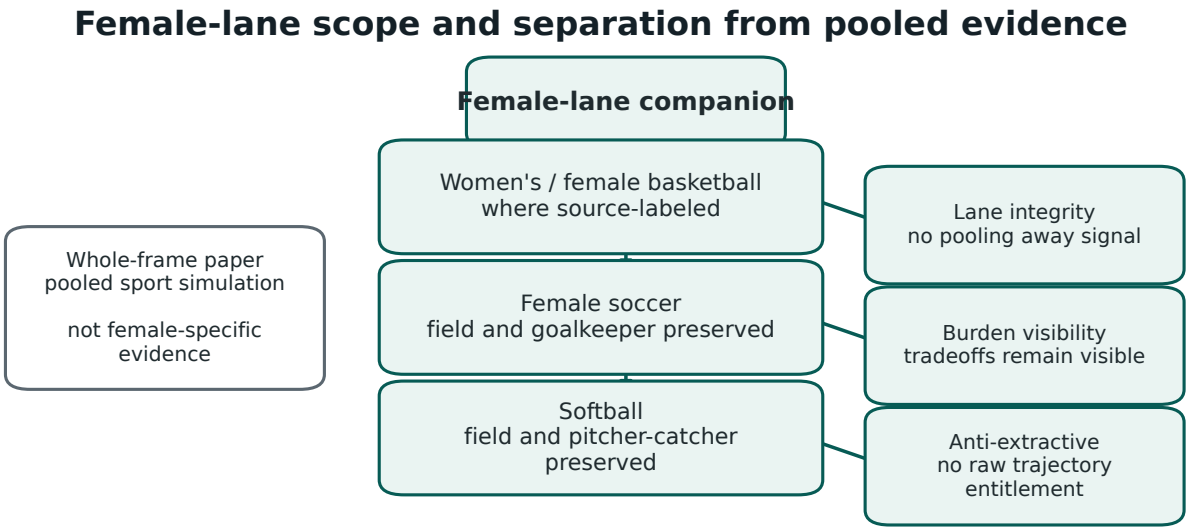


**Figure 1:** Female-stack lane map. The figure defines the companion as a female-lane analysis covering source-labeled women's or female basketball, female soccer, and softball. The whole-frame main paper remains separate and is not treated as female-specific evidence.

## 3. Study design and interpretation safeguards

The companion does not rerun the simulator and does not expand the claim surface. It interprets the female-lane outputs already present in the simulation evidence. Every result is simulator-internal.

The primary displayed summaries are missed-days movement, ACL-family proxy movement, and modeled time-years. For lane $s$, mode $m$, and endpoint $Y$, the companion reports $\Delta_s(Y) = E_w[Y \mid m = SSI, s] - E_w[Y \mid m = Comparator, s]$, with sign interpreted according to the endpoint: lower missed-days and ACL-family proxy values are favorable, while higher modeled time-years are favorable. Position-specific rows are used where they preserve female sport structure, especially soccer field versus goalkeeper and softball field versus pitcher-catcher roles. Governance interpretation is included because data custody is inseparable from safety in low-power settings.

The companion uses four negative-control rules.

1. Female-lane simulation movement is not female-specific clinical validation.
2. ACL-family proxy movement is not diagnosed ACL injury reduction.
3. Days-missed movement is not a promise of fewer real-world missed days.
4. Anti-extractive governance is not a formal privacy proof or device-level privacy validation.

## 3A. Female-stack provenance and transportability boundary

The companion is a scoped female-stack simulation interpretation, not a formal female-specific clinical validation study. The B=180 female-stack outputs are source-reconciled simulation evidence used to study lane integrity, managed-burden transparency, and anti-extractive evidence governance. They do not establish real-world female-specific efficacy, demographic subgroup validation, clinical outcome improvement, or field injury-prevention

effect.

Female-lane transportability requires prospective sport-specific and role-specific data. Women's basketball, female soccer field/goalkeeper structure, and softball field/pitcher-catcher structure illustrate why lane-specific validation matters: each lane may have different exposure rhythm, burden tradeoff, role constraints, medical-adjacent interpretation, and institutional risk.

| Female-lane issue | Current simulation status | Future validation need |
|---|---|---|
| Women's basketball | Preserved as a source-labeled female-stack lane with simulator-internal missed-days, ACL-family proxy, and modeled time-year movement. | Prospective women's basketball data with common retained-time, burden, terminal-proxy, event-history, and sensitivity fields. |
| Female soccer field/goalkeeper | Position-specific structure is treated as analytically meaningful rather than collapsed into one generic cohort. | Role-specific exposure capture, workload rhythm, medical adjudication, and governance review. |
| Softball pitcher/catcher | Managed-burden tradeoff is explicitly visible instead of hidden behind favorable movement. | Pitcher/catcher workload, recovery, restriction, and adjudicated outcome data under bounded access rules. |
| Managed-burden tradeoff | The companion treats favorable proxy movement and increased managed burden as a scientific tradeoff, not a contradiction to hide. | Field protocols that test whether managed burden is acceptable, contestable, non-punitive, and clinically meaningful. |
| Anti-extractive governance | Release rules are described as part of the evidence surface, not as an afterthought. | Consent, revocation, role separation, appeal, and misuse-prevention tests in real institutions. |
| Demographic subgroup validation | Not claimed. Female-stack simulation evidence is not equivalent to demographic validation. | Prospective, community-reviewed, independently governed studies with adequate sample design and protected-use constraints. |

The main manuscript supplies whole-frame B=390 context. This companion supplies female-stack B=180 lane interpretation. The engineering technical supplement defines the model-family and SSES mechanics used to keep those two claim surfaces separate.

# 4. Female-stack analytic model layer

The Sovereign Structural Evidence Stack (SSES) is the post-run evidence-governance layer used in this companion to keep female-stack interpretation tied to source artifacts, scope boundaries, and non-overclaiming rules. SSES does not create new simulation results or convert female-lane simulation findings into demographic subgroup validation. Its role here is narrower and stricter: preserve female-lane provenance, identify managed-burden tradeoffs, and keep public evidence release aggregate, pathway-level, and claim-bounded.

## 4.1 SSES portability and female-lane review

Although SSES is introduced through LAKANA SSI, its female-lane use is portable. Any simulation or quantitative study that reports sex-stratified or female-lane results can use the same evidence-governance pattern: preserve the lane label, require source linkage, pair denominators with event claims, distinguish retained-time movement from burden movement, and prevent public evidence from becoming unrestricted raw-subject exposure. In a non-LAKANA women's sport simulation, SSES would not prove that a model protects female athletes. It would prove that female-lane claims are source-linked, not silently pooled, not denominator-free, not sensitivity-blind, and not released beyond the stated evidence boundary.

This matters because the main methodological failure in female-lane research is often not only lack of data; it is loss of lane identity. SSES makes that loss auditable. Its current limitation is that it is novel and first demonstrated here, so future work should benchmark the same lane-preservation and claim-eligibility rules across independent simulations and empirical studies.

The companion is not limited to a single weighted-mean table. It uses a scoped female-stack model layer: retained-time and burden summaries, Aalen-Johansen cumulative-incidence summaries, Fine-Gray subdistribution summaries, Markov pathway logic, female-stack MEBVB precision, and RET-BURD retained-time/burden classification. These models do not convert the companion into field validation. They make the female-lane evidence harder to erase because multiple outputs have to be interpreted together.

The female-stack precision and burden-surface results are summarized below. The female stack contains B=180 effective precision blocks and 15,000,000 apparent simulated athlete-years. The MEBVB interval is a simulator-internal precision result, not a real-world burden-reduction estimate. The RET-BURD table is a retained-time/burden classification, not a claim that restriction is automatically good or bad.

| Female-stack quantity | Value |
|---|---|
| Effective precision blocks | 180 |
| Apparent simulated athlete-years | 15,000,000 |
| Mean burden-delta | 2,696,116.5081 |
| MEBVB epsilon | 415,724.5744 |
| MEBVB precision interval | [2,280,391.9337, 3,111,841.0825] |
| RET-BURD eligible blocks | 180 |
| Dominant favorable blocks | 162 |
| Managed-burden tradeoff blocks | 18 |
| Adverse / ambiguous blocks | 0 |

The source-labeled female-lane mean summaries show why the companion is a lane-integrity paper rather than a pooled-subgroup appendix.

| Lane | Delta missed days | Delta recognition | Delta peak bio-damage |
|---|---|---|---|
| Female soccer | -68.31 | 0.119 | 0.0056 |
| Softball | -38.43 | 0.048 | 0.0022 |
| Women basketball | -77.79 | 0.181 | 0.0040 |

| Lane | Comp yrs | SSI yrs | Delta yrs |
|---|---|---|---|
| Female soccer | 0.2496 | 0.4701 | 0.2205 |
| Softball | 0.4462 | 0.5948 | 0.1486 |
| Women basketball | 0.1935 | 0.4495 | 0.2559 |

The event-history layer gives the female stack a second, independent check on terminal-proxy movement. Fine-Gray summarizes subdistribution behavior under competing terminal pathways. Aalen-Johansen summarizes cumulative incidence. These are simulator-internal event-history summaries and not clinical incidence estimates.

| Lane | Event | Fine-Gray HR |
|---|---|---|
| Women basketball | ACL | 0.1215 [0.1189, 0.1242] |
| Women basketball | Attrition | 14.6571 [14.1650, 15.1664] |
| Female soccer | ACL | 0.1491 [0.1459, 0.1523] |
| Female soccer | Attrition | 7.2520 [7.0675, 7.4415] |
| Softball | ACL | 0.0604 [0.0577, 0.0632] |
| Softball | Attrition | 2.7184 [2.6768, 2.7607] |

| Lane | Event | AJ comp | AJ SSI | AJ delta |
|---|---|---|---|---|
| Women basketball profile | ACL | 0.9146 | 0.2281 | -0.6866 |
| Women basketball profile | Attrition | 0.0854 | 0.7713 | 0.6859 |
| Female soccer | ACL | 0.8368 | 0.2195 | -0.6172 |

| Lane | Event | AJ comp | AJ SSI | AJ delta |
|---|---|---|---|---|
| Female soccer | Attrition | 0.1632 | 0.7799 | 0.6167 |
| Softball | ACL | 0.4853 | 0.0393 | -0.4460 |
| Softball | Attrition | 0.5147 | 0.9599 | 0.4452 |

## 5. Female-lane results

Figure 2 gives the companion's high-level evidence map. It is designed as a public research figure: the lane, movement summaries, and claim boundary are visible without relying on internal documentation.

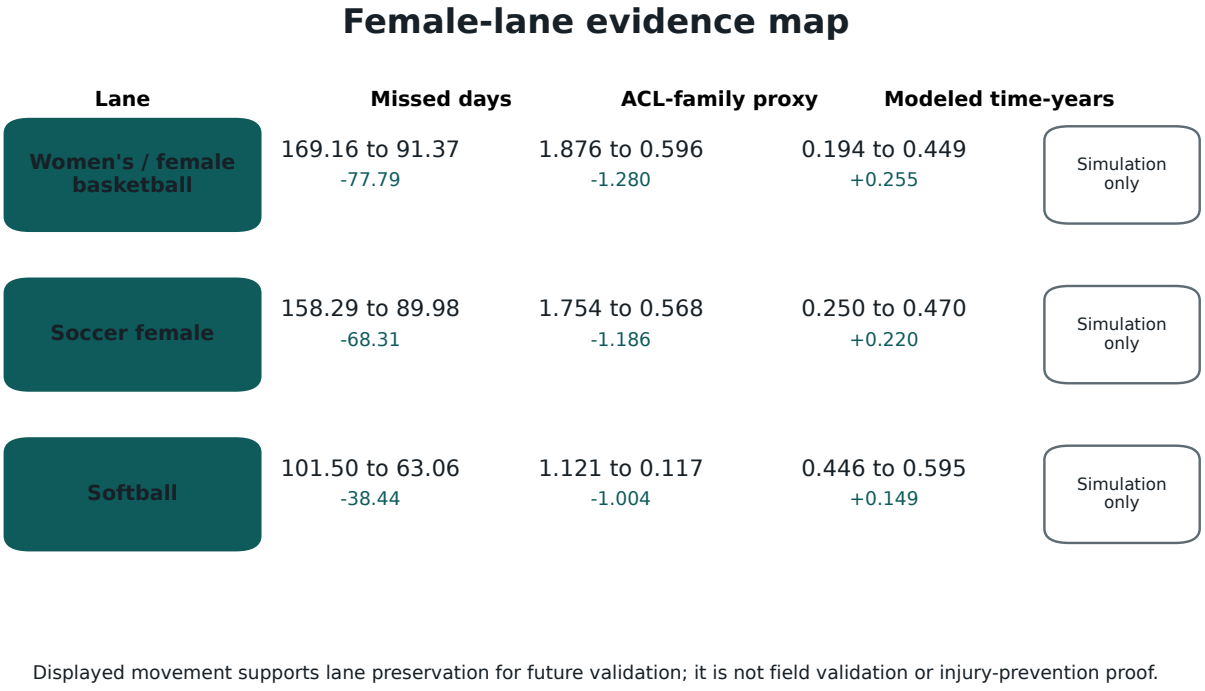


**Figure 2:** Female-lane evidence map. The figure summarizes source-labeled women's or female basketball, female soccer, and softball evidence, including missed-days movement, ACL-family proxy movement, modeled time-years, and claim boundaries. These are simulator-internal pathway changes, not field validation or injury-prevention proof.

Across the displayed female-lane evidence, missed-days movement, ACL-family proxy movement, and modeled time-years all moved in favorable directions inside the simulator. The companion does not interpret those changes as real-world effect. It interprets them as evidence that female lanes are strong enough to deserve first-order validation rather than post-hoc subgroup treatment.

## 6. Female soccer: position-specific evidence

Female soccer illustrates why a single pooled female-soccer row is not enough. The field-player and goalkeeper rows show different movement patterns. The field row reported greater retained-time movement and larger days-missed reduction, while the goalkeeper row reported a larger completed-season movement and a different recognition pattern. The point is not that one position is better. The point is that position-specific exposure structure matters.

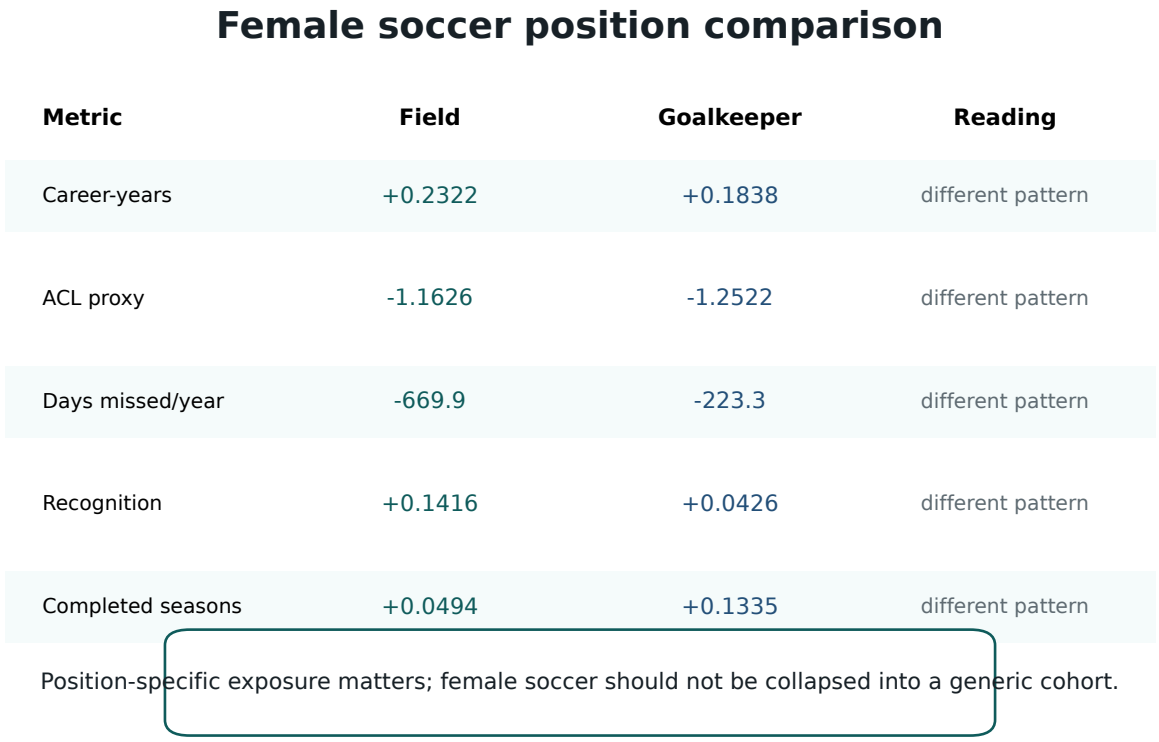


**Figure 3:** Female soccer position comparison. The figure compares simulator-internal field and goalkeeper rows. It shows why female soccer should not be collapsed into one generic cohort and why future validation should preserve role-specific exposure structure.

This result is a methodological warning. Female soccer validation should distinguish field players and goalkeepers, should preserve workload and movement context, and should not generalize from one role to the other without evidence.

## 7. Softball: the managed-burden tradeoff

Softball is the most important cautionary lane in the companion. The softball field row and pitcher-catcher row do not tell the same story. The field row shows favorable movement across retained time, ACL-family proxy, days missed, recognition, and completed seasons. The pitcher-catcher row shows favorable retained-time and ACL-family proxy movement while also showing increased simulator-implied days missed.

That is not a contradiction. It is the central burden-visible lesson of the companion. A system can redirect modeled subjects away from terminal-proxy pathways while increasing managed burden in a high-load role. This must remain visible, especially in sports where playing time, scholarship status, roster position, and coach trust can be affected by restriction decisions.

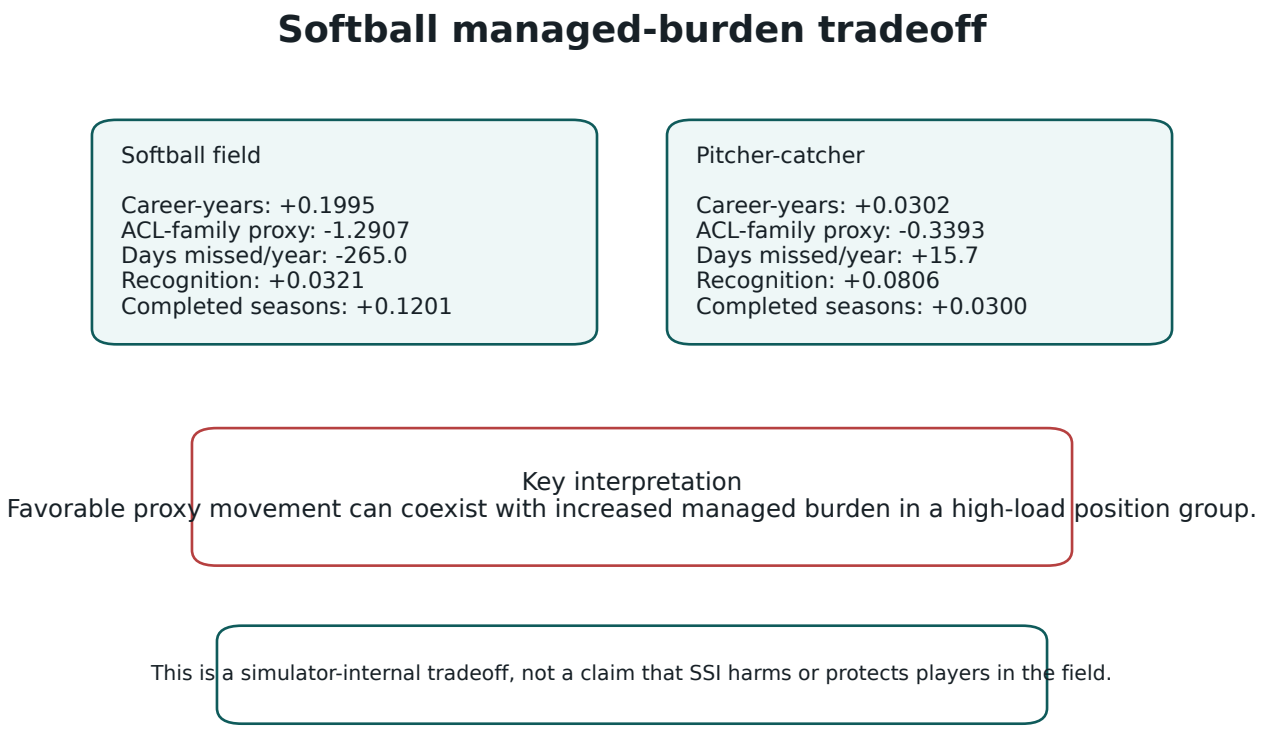


**Figure 4:** Softball managed-burden tradeoff. The figure compares softball field and pitcher-catcher rows. It preserves the cautionary result that favorable proxy movement can coexist with increased simulator-implied days missed in a high-load position group. It is not a claim that SSI harms or protects players in the real world.

Future softball validation should therefore measure not only terminal proxies and exposure, but also restriction acceptability, appeal rights, medical independence, coach access, and whether managed burden is protective, punitive, or both under institutional pressure.

## 8. Women's basketball lane

Where a source-labeled women's or female basketball lane is present, the companion preserves it. The displayed evidence map reports missed days moving from 169.16 to 91.37, cumulative ACL-family proxy from 1.876 to 0.596, and modeled time-years from 0.194 to 0.449. These are lane-specific simulation contrasts. They are not evidence of real-world improvement in women's basketball. They support the methodological claim that women's basketball should remain an explicit validation lane in future work.

## 9. Anti-extractive governance as a scientific requirement

Safety research can become extractive when it asks athletes or workers to provide intimate bodily data while giving institutions broad access to vulnerability signals. This risk is higher where people have less bargaining power: under-resourced programs, HBCU and community settings, rural schools, inner-city schools, scholarship-dependent athletes, and workers whose income depends on compliance.

The companion treats anti-extractive governance as part of scientific validity. If a system cannot be evaluated without raw trajectory entitlement, then its evidence process may be unsafe even before deployment. Figure 5 shows the public release boundary used for this companion: aggregate artifacts, pathway-level summaries,

claim-bounded releases, checksum-tracked files, and adjudicated evidence are allowed; unrestricted raw subject trajectories and coercive query access are not.

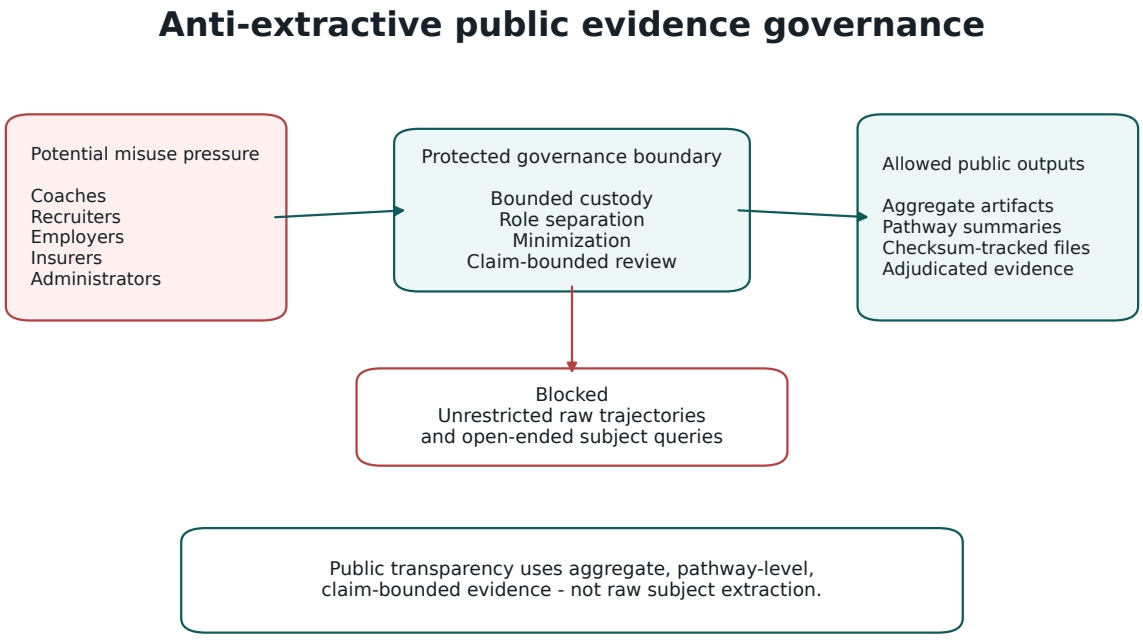


**Figure 5:** Anti-extractive public evidence-release governance. The schematic shows how bounded custody, role separation, minimization, non-surveillance constraints, claim-bounded public review, and adjudicated release prevent public evidence from becoming unrestricted raw subject trajectories. This is a governance and release-boundary figure only, not a formal privacy proof, device-level privacy validation, or field anti-surveillance validation.

## 10. Negative controls and alternative explanations

The female-lane results do not show demographic subgroup validation. Race, ethnicity, disability, socioeconomic status, geography, school resources, and institutional power were not modeled as outcome strata.

The results do not show female-specific clinical effect. The outputs are simulated pathway variables, not clinical diagnoses or adjudicated injuries.

The results do not show that more restriction is always better. The softball pitcher-catcher result shows exactly why burden must be reported as a tradeoff.

The governance analysis does not show formal privacy. It specifies a public evidence-release boundary; it does not prove differential privacy, de-identification, anonymity, no re-identification risk, telemetry security, or device-level privacy.

## 10A. Equity-variable boundary and subgroup non-claim

The companion uses equity language in a methodological sense: lane integrity, non-extractive release governance, and protection against subgroup erasure. It does not model race, ethnicity, socioeconomic status, disability, rurality, HBCU participation, insurance access, school resources, or neighborhood conditions as outcome-generating covariates. Therefore, the companion must not be read as evidence of minority subgroup efficacy or demographic outcome improvement.

The valid equity claim is narrower: a safety-simulation paper should not collapse source-labeled lanes, should not convert athlete trajectories into unrestricted institutional surveillance, should not hide managed burden behind favorable terminal-proxy movement, and should not present public evidence without contestable source boundaries. Prospective minority-protective validation requires community-reviewed design, consent and revocation rules, protected-use constraints, adequate sample design, and independent governance before any demographic-outcome claim is made.

## 11. Limitations

First, the companion is simulation-bounded. It does not establish field effectiveness, clinical validity, injury prevention, return-to-play authority, or regulatory readiness.

Second, the female-lane evidence is limited to source-labeled lanes and available simulator outputs. It cannot replace prospective female-athlete studies.

Third, ACL-family proxy and missed-days movement are simulator-internal pathway variables. They should not be converted into clinical outcome claims.

Fourth, the companion interprets equity governance, but does not compute equity-stratified outcome tables. The governance argument is therefore a study-design and release-boundary argument, not a demographic performance result.

Fifth, the anti-extractive framework has not been field-tested. It needs prospective validation of consent, revocation, access control, appeal rights, and misuse prevention.

## 12. Ten-year roadmap for female-lane and minority-protective validation

A serious validation program should proceed in stages.

1. **Female soccer role validation:** test field-player and goalkeeper pathways separately with instrumented exposure, recovery, and adjudicated outcomes.
2. **Softball workload validation:** separate field, pitcher, catcher, tournament, heat, and recovery burdens rather than pooling them.
3. **Women's basketball validation:** preserve source-labeled women's basketball lanes and maintain the whole-frame distinction between basketball_female and basketball_male rather than treating basketball as a generic pooled sport. Matched male/female basketball public tables should be added only when both lane outputs are source-reconciled.
4. **Governance trials:** test whether role separation, revocation, appeal rights, and no-punitive-use rules work under real institutional pressure.
5. **Community partnership:** build HBCU, rural, inner-city, and community validation protocols with local governance before data collection.
6. **Workforce extension:** test whether burden-visible, non-surveillance structural-load evaluation can translate to physically demanding work without becoming productivity surveillance.

## 13. Data and public evidence availability

The public package contains manuscripts, figures, references, figure registry, and checksum manifests. It does not publicly release raw subject trajectories, proprietary thresholds, scoring weights, trigger logic, raw trace schemas, custody internals, key-management internals, or sensor-fusion coefficients. That boundary is intentional. Public review should be possible without unrestricted extraction.

## 14. Conclusion

This companion paper shows why female-lane evidence cannot be treated as an afterthought in structural-load safety research. Women's basketball, female soccer, and softball are not interchangeable labels inside a pooled athlete average; they are source-labeled lanes whose retained-time movement, missed-days movement, terminal-proxy behavior, recognition changes, event-history structure, and burden tradeoffs must remain visible if a safety framework is to be evaluated honestly.

The female-stack evidence supports a disciplined interpretation rather than a broad claim of real-world protection. The reported patterns show favorable simulator-internal movement across retained-time and terminal-proxy families, while the softball and position-specific soccer results demonstrate why managed burden must be interpreted alongside retained time. That combination is the scientific point: a system can look favorable on a terminal-proxy endpoint while still shifting restriction, chronic burden, exposure time, or attritional structure in ways that require transparent reporting.

The governance contribution is inseparable from the analytic contribution. Female-lane and minority-protective safety research cannot rely on unrestricted raw trajectories, silent institutional access, or generic subgroup averaging. Public evidence should be aggregate, pathway-level, claim-bounded, source-linked, and contestable. In this companion, SSES provides the evidence-governance grammar for that standard without converting simulation outputs into demographic validation, clinical proof, or field efficacy.

The result is a public reporting model for female-lane structural intelligence: preserve the lane, disclose the tradeoff, show the pathway, bound the claim, and prevent transparency from becoming extraction. Future work should move from simulator-internal evidence to governed validation with consented measurement, community oversight, female-sport-specific exposure data, basketball sex-lane public tables, externally adjudicated outcomes, and formal anti-misuse controls before any deployment claim is made.

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The bibliography below uses the same public citation posture as the main paper: methods and domain references support the interpretation of a simulation study, while LAKANA DOI records identify related public materials and are not treated as validation evidence.


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