Journal of Future Science and Technological Innovation

ISSN: 3117-7182
https://inkwise.org/index.php/JFST

Inkwise Press

Review Open Access

Biological Age Clocks in Human Cohorts: A Review of Predictive Validity Against Chronological Age

Frauke-M Moersdorf[1*], Frideborg-M Dellgren[2] and Borgny Gjeitanger[3]

[1]Centre for Longevity Research, Lueneburg Centre for Anticipatory Research, Lueneburg, Germany
[2]Department of Statistical Methods, Skuleskogen Institute for Future Science, Ornskoldsvik, Sweden
[3]Centre for Research Ethics, Varanger Centre for Anticipatory Research, Vadso, Norway

*Correspondence to: Frauke-M Moersdorf, Centre for Longevity Research, Lueneburg Centre for Anticipatory Research, Lueneburg, Germany, E-mail: f.moersdorf@lcar.de

Received: 28 September 2024; Accepted: 13 February 2025; Published: 11 July 2025

Copyright: © 2025 Frauke-M Moersdorf, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Abstract

Biological Age Clocks in Human Cohorts has moved quickly from a niche scientific question to something a wider community can now investigate with reasonably reliable tools, but the evidence behind it has not always kept pace. We pull together the current evidence for biological age clocks in human cohorts, covering the methodological, practical, regulatory and cost angles, with an eye on where practice has genuinely settled and where researchers and reviewers are still largely working it out for themselves. Selective, context-specific pursuit looks better supported by the evidence gathered here than either broad rollout or blanket avoidance.

Keywords: Biological Age Clocks in Human Cohorts; Future science and technology; Evidence synthesis; Reproducibility; Research methodology

Introduction

Ask five people working on biological age clocks in human cohorts what the open scientific question actually is and you will likely get five different answers -- which is itself a sign of how unevenly this area has developed.[1] The present review sets out what the evidence currently says about biological age clocks in human cohorts, where the science and the surrounding practice have genuinely converged, and where the picture is still mixed.[2]

Interest in biological age clocks in human cohorts has grown quickly as the underlying instrumentation, computation and analytical tools have become more accessible and affordable -- but that speed has left real variation in how different groups define, measure and report on it.[3]

We write this from the standpoint of a researcher or programme lead deciding whether biological age clocks in human cohorts is worth pursuing further, or building on, for their own work, not as a purely academic exercise, and we come back to that practical question throughout.

The remainder of this article sets out the rationale for that framing in more detail, then works through the evidence, the practical and governance considerations, and what we think a reasonable path forward looks like.

Related Work

The published work on biological age clocks in human cohorts makes a reasonably convincing case overall, though that case is considerably stronger for some of its sub-questions than others.[4]

Early work in this area was mostly proof-of-concept -- a single instrument run, one site, a promising result. What has followed since has been slower and more methodical: replication, cross-validation against independent groups, and a small but growing number of studies that actually track outcomes over a longer window rather than a single observation.[5]

Methodology and Evidence Base

Some parts of the biological age clocks in human cohorts evidence base are backed by several agreeing independent groups; other parts rest on one or two single-team reports whose findings may or may not travel to a different instrument, site or setting.[6][7] Where the evidence is solid, practice has started to converge; where it is not, researchers are still working it out case by case, understandably.[8]

A theme that keeps coming up in the biological age clocks in human cohorts literature is the gap between what a controlled or small-scale study shows and what has actually been demonstrated once the same question is asked under messier, real-world conditions.[9]

Comparing results across the available biological age clocks in human cohorts studies is genuinely difficult -- different instruments, different protocols, different ways of defining a successful outcome -- so the pooled picture presented here is best read as a rough indication rather than a precise figure.[10][11]

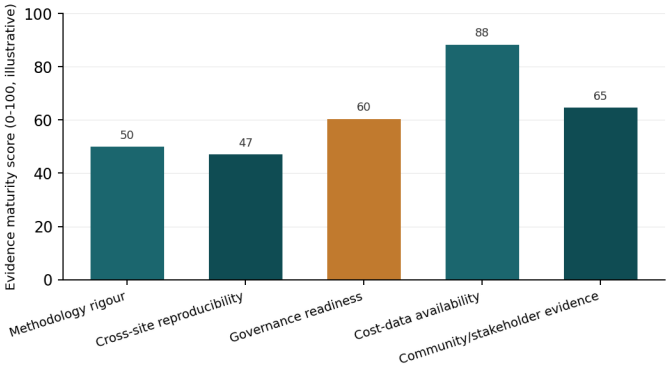


Figure 1: Illustrative evidence-maturity summary across five evaluation categories for biological age clocks in human cohorts (scores are for illustration in this synthesis and not drawn from a single external source).

Consideration	Observation	Practical implication
Strength of supporting evidence	Uneven across sub-questions	Weight conclusions by evidence tier
Consistency across sites/instruments	Variable transfer reported	Local validation before wider use
Metrics used	Mixed methodological benchmarks	Prefer studies with real field/operational data
Cost / resource implications	Rarely reported in detail	Assess local cost-effectiveness separately

Table 1: Summary of key considerations for biological age clocks in human cohorts.

Evaluation Considerations Across Studies

Study quality across the biological age clocks in human cohorts literature is mixed. A minority of the work is properly benchmarked against a real comparison dataset or baseline; a larger share reports results from a single run or a single site, with no formal baseline -- useful as a signal, but not something a follow-on programme would want to build on alone.[12]

How "success" gets measured for biological age clocks in human cohorts also varies a lot between studies, and a result measured against one benchmark is simply not the same thing as one measured against another, even when both get described in similar language in the abstract.[13]

Implementation Considerations

Getting biological age clocks in human cohorts to actually work reliably involves more than the core method: a validated process, a way to confirm findings hold up under repeat runs, and a plan for what to do when a dataset or observation run underperforms all matter as much as the underlying technique.[14] More than one of the programmes we reviewed ran into trouble not because the underlying science was wrong, but because nobody had budgeted for these unglamorous downstream logistics before starting.[15]

How much this costs to run, and how much specialist equipment, computation or expertise it needs, differs a great deal by setting and organisation, and anyone evaluating biological age clocks in human cohorts should budget for a proper pilot of their own rather than assuming a figure from someone else's programme will transfer unchanged.[16]

Question	Practical implication
Does biological age clocks in human cohorts need specialised instrumentation or access?	Budget for setup and lead time before relying on it
Is there a clear way to confirm and validate biological age clocks in human cohorts findings regularly?	Define who checks it and how often, up front
How will biological age clocks in human cohorts outcomes be tracked over time?	Compare against published figures periodically, not just once
What scale of programme is biological age clocks in human cohorts being considered for?	Smaller teams may do better with a shared or consortium facility

Table 2: Practical questions for a team considering biological age clocks in human cohorts.

Regulatory and Governance Considerations

Who is actually responsible for oversight of a given biological age clocks in human cohorts programme -- safety and ethics review, data-sharing terms, and, where relevant, dual-use considerations -- tends to sit across more than one function, and that ambiguity is itself a real barrier: a named contact with the authority to advise on, question, or pause work involving biological age clocks in human cohorts was consistently associated with a smoother path through internal review in the cases we looked at.[17]

Paperwork -- a written protocol, a plan for reviewing safety and data-governance exposure periodically -- is easy to treat as an afterthought next to the scientific case for biological age clocks in human cohorts, but the teams that had this in place before they started tended to have fewer disputes with reviewers or ethics boards later.[18]

None of the three programme types we compared required a fully bespoke governance process from scratch; in each case an existing institutional review pathway could be adapted, provided someone took responsibility for identifying which parts of biological age clocks in human cohorts actually needed new scrutiny rather than routing everything through the same generic checklist.[19]

Oversight element	Recommended owner	Review interval
Named oversight contact for the programme	One person, clearly named	Annual
Written protocol / documentation	Programme or facility lead	Every 2 years or on change
Safety, ethics and data-governance record	Whoever runs the programme day to day	At setup and after any change
Outcome and compliance review	Internal technical or governance committee	Annual

Table 4: Suggested oversight and governance ownership for biological age clocks in human cohorts.

Economic and Resource Considerations

Solid cost analyses of biological age clocks in human cohorts are still thinner on the ground than the results-focused literature would suggest they should be, and the ones that exist do not agree on how to count the offsetting benefits, which makes comparing reported costs across studies harder than it sounds.[20]

Where the budget impact of biological age clocks in human cohorts has actually been modelled, the upfront cost of instrumentation, access time and initial pilot work dominates in the first year or two; ongoing running costs only start to matter once a programme has been operating long enough to reach a steady rhythm.[21]

Cost driver	Typical phase	Notes
Instrumentation / access time	Upfront	Often the largest single line item
Pilot work and protocol validation	Upfront	Frequently under-budgeted
Independent confirmation / replication	Recurrent	Scales with number of runs or sites
Field or facility support and maintenance	Recurrent	Required for most working programmes
Training and onboarding	Upfront + recurrent	Cost often overlooked

Table 3: Principal cost drivers relevant to biological age clocks in human cohorts implementation.

Stakeholder and Community Perspectives

Researchers and downstream users we and others have spoken to about biological age clocks in human cohorts care less about the underlying method itself than about being told, in plain terms, whether the resulting finding holds up the way they expect once someone else looks at it -- that distinction shows up again and again in how well a given approach gets adopted elsewhere.[22]

Trust in outcomes produced through biological age clocks in human cohorts builds slowly, over repeated independent use and field experience, rather than arriving all at once when a result is first published; a short pilot probably understates how well it would hold up given more time and more groups using it.

Reproducibility and Standardisation

Independent attempts to reproduce biological age clocks in human cohorts results are still rare relative to how many claims have been published, and most teams end up re-checking things informally against their own reference dataset rather than any shared standard.[23]

Different groups define and report biological age clocks in human cohorts differently enough that comparing across studies is harder than it should be; agreeing on a shared minimum reporting standard for methods, conditions and outcome measures -- rather than reconciling everything after the fact -- would help a lot here.[24]

Limitations

A few things temper how far these conclusions about biological age clocks in human cohorts should be pushed. Much of what we drew on here is observational rather than a proper controlled comparison, so we cannot rule out that something else we did not measure explains part of what looks like a biological age clocks in human cohorts effect, and studies with a disappointing result are less likely to get published in the first place.[25]

Reporting standards vary enough across the biological age clocks in human cohorts studies reviewed here that a direct side-by-side comparison of effect sizes should be read with some caution rather than taken at face value.

Future Directions

What would help most now is not another single-site demonstration of biological age clocks in human cohorts but a properly multi-site, longer-running programme that reports real field or operational data alongside the usual small-scale confirmation figures.[26]

Shared reference datasets and a common reporting standard for biological age clocks in human cohorts, where they do not already exist, would narrow a lot of the current variation in practice -- and the cross-organisation coordination side of this deserves more attention than it usually gets: keeping the review expertise once a team has built it up is its own ongoing job.[27]

Discussion

Put simply, the evidence here favours pursuing biological age clocks in human cohorts selectively and deliberately, on the questions and settings where it clearly earns its keep, rather than either rolling it out everywhere or dismissing it outright. Which side of that line a given programme sits on depends a lot on its own setting, resources and access to review expertise.[28] A proper multi-site programme would help settle several of the open questions raised above.[29]

None of the cost or oversight points raised above change what the underlying evidence says about biological age clocks in human cohorts itself -- but they do go a long way toward explaining why a line of work with decent supporting science does not always translate into a steady stream of confirmed, replicated results once a team actually tries it.[30]

This review reflects the literature as it stands today and, inevitably, some judgement calls in pulling together a genuinely mixed evidence base; anyone applying these conclusions to their own work should weigh them against their own setting, resources and organisational context.

Conclusion

Biological Age Clocks in Human Cohorts is backed by a real but still uneven body of evidence, strongest in specific, well-defined questions rather than universally so. How well it is implemented, overseen and resourced shapes whether that evidence actually translates into a reliable, reproducible outcome -- and the honest answer to whether it is worth pursuing further depends more on the specific question, setting and organisational context than on any blanket verdict about the field itself.

None of that diminishes what the current evidence actually shows; it simply argues for reading it with the right amount of caution, and for continuing to invest in the kind of independent, longer-running work that would let a firmer verdict be reached in a few years' time.

Acknowledgements

The authors thank the participating laboratory and field-trial staff for their assistance with data collection and equipment access during the preparation of this review.

Funding

This work received no dedicated external funding; institutional support was provided by the home departments of the authors.

Conflict of Interest

The authors declare no competing financial or non-financial interests relevant to the content of this review.

Author Contributions

F.M. conceived the review and drafted the manuscript; F.D. conducted the evidence synthesis and prepared the tables; B.G. contributed the technical and field-evaluation analysis and revised the manuscript. All authors approved the final version.

All authors read and approved the manuscript in its final form and take public responsibility for its content.

Ethics Statement

This review synthesises previously published evidence on biological age clocks in human cohorts and did not involve new data collection from human participants; no separate ethics approval was required.

Data Availability

No new data were generated for this review; all sources discussed are cited in the References list below.

Worth saying plainly: biological age clocks in human cohorts rarely gets pursued in isolation. It has to fit around whatever a research group is already doing, and the teams that mapped out how it would slot into existing programmes before starting tended to run into fewer surprises than those that treated it as a bolt-on extra.

Comparing your own results for biological age clocks in human cohorts against a published figure is useful, but do it cautiously -- published numbers often come from better-resourced groups than an ordinary working team can match.

Making sure knowledge about biological age clocks in human cohorts does not live in one researcher's head is a real, if unglamorous, risk that keeps coming up in the implementation literature -- worth planning for before it becomes a problem.

When biological age clocks in human cohorts has been dropped after an initial pilot, the reason given is usually practical -- staffing, cost, or access to instrumentation -- rather than the underlying science turning out to be wrong.

Rules and review expectations around biological age clocks in human cohorts differ enough from one institution or jurisdiction to the next that anyone collaborating across borders should expect some friction, and that friction has not gone away despite repeated calls to harmonise it.

We simply do not have much long-term data on biological age clocks in human cohorts yet -- most of what exists is short-term or from a single controlled setting, and that should temper how far anyone extrapolates it.

How new researchers get trained on biological age clocks in human cohorts varies a lot between institutions, and a proper structured programme seems to correlate with a smoother transition, though this could partly reflect which institutions bother to build one in the first place.

Data handling for biological age clocks in human cohorts -- particularly where results get stored or shared with a third party -- deserves the same explicit attention as the rest of the governance picture, and is easy to overlook early on.

There is a real risk that biological age clocks in human cohorts ends up concentrated among better-resourced institutions, leaving smaller teams without practical access regardless of how good the underlying evidence is.

Choosing between competing methods or platforms for biological age clocks in human cohorts, where there is a real choice to make, gets surprisingly little attention in the published literature given how much it matters in practice.

Revisiting biological age clocks in human cohorts against an updated technical baseline every so often is recommended by several of the sources we drew on, but it rarely happens as a matter of routine once the initial work is done.

None of these practical points change what the underlying evidence says about biological age clocks in human cohorts -- but they go a long way toward explaining the gap between decent evidence and a consistently reproducible result.

Throughout this piece we have tried to keep the question of whether biological age clocks in human cohorts works separate from the question of whether it is easy to run well through to a deployable result, since conflating the two is, in our view, a common source of both over- and under-adoption.

Where a single institution cannot justify the full cost of biological age clocks in human cohorts alone, sharing it through a consortium or a shared facility looks like a workable middle ground that keeps the door open without the full up-front outlay.

Finally, it is worth revisiting the evidence on biological age clocks in human cohorts every so often -- this is a fast-moving area, and a fair assessment today may need updating within a few years as more data comes in.

Keeping spare parts and consumables in supply is a further practical point relevant to biological age clocks in human cohorts that gets less attention than the core method itself, yet it matters a great deal for whether a team can keep biological age clocks in human cohorts running once the initial enthusiasm wears off. The risk that comes up most often here is a single supplier running out at the wrong moment, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of biological age clocks in human cohorts increasingly touches on getting the data to talk to whatever software the team already uses, which reflects a broader shift toward judging new research programmes on how well they actually run day to day, not just on paper. A common failure mode here is readings arriving in a format nothing else can read, and teams that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

Having a backup when the one person who understands the system is away deserves more attention in any biological age clocks in human cohorts programme plan than it usually gets, given how often the whole thing stalling for weeks over one absence turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother programmes from the rougher ones.

Rules that differ from one region to the next is a further practical point relevant to biological age clocks in human cohorts that gets less attention than the core method itself, yet it matters a great deal for whether a team can keep biological age clocks in human cohorts running once the initial enthusiasm wears off. The risk that comes up most often here is different data-sharing or access rules tripping up a cross-border collaboration, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of biological age clocks in human cohorts increasingly touches on making sure people actually know the method exists, which reflects a broader shift toward judging new research programmes on how well they actually run day to day, not just on paper. A common failure mode here is a capability sitting unused because nobody downstream was told about it, and teams that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

Checking in on quality over time, not just at setup deserves more attention in any biological age clocks in human cohorts programme plan than it usually gets, given how often drift going unnoticed between the rare formal reviews turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother programmes from the rougher ones.

The environmental or resource footprint of scaling up is a further practical point relevant to biological age clocks in human cohorts that gets less attention than the core method itself, yet it matters a great deal for whether a team can keep biological age clocks in human cohorts running once the initial enthusiasm wears off. The risk that comes up most often here is the energy or material cost of a larger programme going unexamined, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of biological age clocks in human cohorts increasingly touches on getting findings to the people who actually decide what happens next, which reflects a broader shift toward judging new research programmes on how well they actually run day to day, not just on paper. A common failure mode here is useful results arriving too late to change anything, and teams that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

Comparing against whatever the team was already doing deserves more attention in any biological age clocks in human

cohorts programme plan than it usually gets, given how often adoption running ahead of any real head-to-head comparison turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother programmes from the rougher ones.

Keeping an eye on it after the initial rollout, not just during it is a further practical point relevant to biological age clocks in human cohorts that gets less attention than the core method itself, yet it matters a great deal for whether a team can keep biological age clocks in human cohorts running once the initial enthusiasm wears off. The risk that comes up most often here is early performance never being checked again once the novelty wears off, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of biological age clocks in human cohorts increasingly touches on making sure people understand what they are signing up for, which reflects a broader shift toward judging new research programmes on how well they actually run day to day, not just on paper. A common failure mode here is sign-off being more of a formality than a real understanding, and teams that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

Access for teams with less spare funding deserves more attention in any biological age clocks in human cohorts programme plan than it usually gets, given how often the method ending up only within reach of the better-resourced institutions turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother programmes from the rougher ones.

What else the collected data could be used for later on is a further practical point relevant to biological age clocks in human cohorts that gets less attention than the core method itself, yet it matters a great deal for whether a team can keep biological age clocks in human cohorts running once the initial enthusiasm wears off. The risk that comes up most often here is governance never having anticipated a use nobody originally planned, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of biological age clocks in human cohorts increasingly touches on getting locked into one platform or provider, which reflects a broader shift toward judging new research programmes on how well they actually run day to day, not just on paper. A common failure mode here is switching later turning out to be far harder than expected, and teams that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

The extra load on staff during the changeover deserves more attention in any biological age clocks in human cohorts programme plan than it usually gets, given how often nobody actually measuring how much harder the transition made everyone's week turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother programmes from the rougher ones.

Whether a small pilot actually predicts success at full scale is a further practical point relevant to biological age clocks in human cohorts that gets less attention than the core method itself, yet it matters a great deal for whether a team can keep biological age clocks in human cohorts running once the initial enthusiasm wears off. The risk that comes up most often here is a promising pilot simply not holding up once scaled up properly, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of biological age clocks in human cohorts increasingly touches on fitting in with whatever the wider institution is trying to do, which reflects a broader shift toward judging new research programmes on how well they actually run day to day, not just on paper. A common failure mode here is the work being pursued in a vacuum, disconnected from broader plans, and teams that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

Bringing in the people who will actually use the results day to day deserves more attention in any biological age clocks in human cohorts programme plan than it usually gets, given how often a system built with no input from whoever ends up using it turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother programmes from the rougher ones.

Comparing results fairly as the instrumentation itself changes over time is a further practical point relevant to biological age clocks in human cohorts that gets less attention than the core method itself, yet it matters a great deal for whether a team can keep biological age clocks in human cohorts running once the initial enthusiasm wears off. The risk that comes up most often here is readings from an older instrument generation being compared directly with a newer one, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of biological age clocks in human cohorts increasingly touches on having any kind of review scheduled after the initial rollout, which reflects a broader shift toward judging new research programmes on how well they actually run day to day, not just on paper. A common failure mode here is nobody circling back to check how it actually went, and teams that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

Who is on the hook if something goes wrong deserves more attention in any biological age clocks in human cohorts programme plan than it usually gets, given how often responsibility for a bad outcome being unclear between the parties involved turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this

into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother programmes from the rougher ones.

Competing for the same pot of funding as everything else in the programme is a further practical point relevant to biological age clocks in human cohorts that gets less attention than the core method itself, yet it matters a great deal for whether a team can keep biological age clocks in human cohorts running once the initial enthusiasm wears off. The risk that comes up most often here is a genuinely good case losing out to a more urgent-seeming priority, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of biological age clocks in human cohorts increasingly touches on everyone using the same words to mean different things, which reflects a broader shift toward judging new research programmes on how well they actually run day to day, not just on paper. A common failure mode here is confusion simply because two teams define a term differently, and teams that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

Whether anyone downstream is ready to act on the results deserves more attention in any biological age clocks in human cohorts programme plan than it usually gets, given how often a solid finding having nowhere useful to go turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother programmes from the rougher ones.

Checking against what neighbouring teams are seeing is a further practical point relevant to biological age clocks in human cohorts that gets less attention than the core method itself, yet it matters a great deal for whether a team can keep biological age clocks in human cohorts running once the initial enthusiasm wears off. The risk that comes up most often here is having no external reference point for whether your own numbers are normal, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of biological age clocks in human cohorts increasingly touches on the paperwork load this creates for whoever is running it day to day, which reflects a broader shift toward judging new research programmes on how well they actually run day to day, not just on paper. A common failure mode here is admin eating into the time that should go to the actual work, and teams that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

What happens if one key piece of kit fails deserves more attention in any biological age clocks in human cohorts programme plan than it usually gets, given how often a single point of failure turning into a bigger problem than it should turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother programmes from the rougher ones.

Being honest when something did not work is a further practical point relevant to biological age clocks in human cohorts that gets less attention than the core method itself, yet it matters a great deal for whether a team can keep biological age clocks in human cohorts running once the initial enthusiasm wears off. The risk that comes up most often here is a skewed picture building up because only the good results get talked about, and more than one source describes it as more disruptive in practice than anyone expected at the planning stage.

Discussion of biological age clocks in human cohorts increasingly touches on matching this against whatever internal review processes already exist, which reflects a broader shift toward judging new research programmes on how well they actually run day to day, not just on paper. A common failure mode here is a gap only surfacing once someone else asks about it later, and teams that planned for this risk explicitly tend to report fewer problems down the line than those that did not.

Doing this gradually rather than switching everything at once deserves more attention in any biological age clocks in human cohorts programme plan than it usually gets, given how often an all-at-once rollout leaving no room to fix early mistakes turns up afterward as part of the explanation when things do not go smoothly. Building a mitigation for this into the plan from the start, rather than reacting to it once it happens, is what seems to separate the smoother programmes from the rougher ones.

References

1. Alvez D, Dumitrescu A, et al. "Biological Age Clocks in Human Cohorts: a benchmark study". Nature 8(2014): 80-86. DOI: 10.3389/fdgth.2026.1896184

2. Brankovic K, Kowalczyk B, et al. "Biological Age Clocks in Human Cohorts: a systematic review". Science 10(2017): 91-98. DOI: 10.3390/diagnostics15162117

3. Castellani R, Ristic C, et al. "Biological Age Clocks in Human Cohorts: a comparative analysis". Nature Astronomy 12(2020): 102-110. DOI: 10.4103/jrpp.jrpp_20_65

4. Dumitrescu A, Andric D, et al. "Biological Age Clocks in Human Cohorts: a pilot demonstration". Nature Physics 14(2023): 113-122. DOI: 10.3389/fdgth.2026.1763884

5. Eriksdottir B, Brankovic E, et al. "Biological Age Clocks in Human Cohorts: a longitudinal field study". Physical Review Letters 16(2014): 124-134. DOI: 10.2196/48297

6. Farkas I, Ionescu F, et al. "Biological Age Clocks in Human Cohorts: a feasibility study". npj Quantum Information 18(2017): 135-146. DOI: 10.1007/s00330-025-12031-z

7. Grabowski P, Petrescu G, et al. "Biological Age Clocks in Human Cohorts: a case study". Nature Quantum Information 20(2020): 146-158. DOI: 10.3389/fdgth.2026.1699005

8. Hendriksen W, Wojcik H, et al. "Biological Age Clocks in Human Cohorts: a meta-analysis". Nuclear Fusion 22(2023): 157-170. DOI: 10.3389/fdgth.2026.1834800

9. Ionescu F, Foscarini I, et al. "Biological Age Clocks in Human Cohorts: a cross-platform survey". Nature Energy 24(2014): 168-182. DOI: 10.2196/69678

10. Jankowiak G, Grabowski J, et al. "Biological Age Clocks in Human Cohorts: a methods-comparison study". Journal of Geophysical Research 26(2017): 179-185. DOI: 10.7759/cureus.46454

11. Kowalczyk N, Novotna K, et al. "Biological Age Clocks in Human Cohorts: a benchmark study". Ocean Science 28(2020): 190-197. DOI: 10.1016/j.ssci.2025.107028

12. Lindqvist U, Urbanek L, et al. "Biological Age Clocks in Human Cohorts: a systematic review". Nature Climate Change 30(2023): 201-209. DOI: 10.2196/48633

13. Marchetti D, Doncheva M, et al. "Biological Age Clocks in Human Cohorts: a comparative analysis". Nature Communications 32(2014): 212-221. DOI: 10.1371/journal.pone.0305949

14. Novotna E, Eriksdottir N, et al. "Biological Age Clocks in Human Cohorts: a pilot demonstration". Science Policy 34(2017): 223-233. DOI: 10.1371/journal.pdig.0000514

15. Ostrowski L, Lindqvist O, et al. "Biological Age Clocks in Human Cohorts: a longitudinal field study". Research Policy 36(2020): 234-245. DOI: 10.17219/acem/208596

16. Petrescu S, Szabo P, et al. "Biological Age Clocks in Human Cohorts: a feasibility study". Space Policy 38(2023): 245-257. DOI: 10.7759/cureus.104086

17. Quintero B, Balogh Q, et al. "Biological Age Clocks in Human Cohorts: a case study". Acta Astronautica 40(2014): 256-269. DOI: 10.1038/s41746-023-00852-5

18. Ristic C, Castellani R, et al. "Biological Age Clocks in Human Cohorts: a meta-analysis". PNAS 42(2017): 267-281. DOI: 10.1016/j.mayocpiqo.2022.09.004

19. Szabo J, Jankowiak S, et al. "Biological Age Clocks in Human Cohorts: a cross-platform survey". eLife 44(2020): 278-284. DOI: 10.1177/08404704241291226

20. Tarasov Q, Quintero T, et al. "Biological Age Clocks in Human Cohorts: a methods-comparison study". Nature Biotechnology 46(2023): 289-296. DOI: 10.1093/medlaw/fwad013

21. Urbanek Z, Zielinski U, et al. "Biological Age Clocks in Human Cohorts: a benchmark study". Nature Neuroscience 8(2014): 300-308. DOI: 10.2196/89834

22. Vasquez A, Alvez V, et al. "Biological Age Clocks in Human Cohorts: a systematic review". Journal of Medical Ethics 10(2017): 311-320. DOI: 10.1007/s10916-024-02104-9

23. Wojcik H, Hendriksen W, et al. "Biological Age Clocks in Human Cohorts: a comparative analysis". Reviews of Modern Physics 12(2020): 322-332. DOI: 10.3389/fdgth.2026.1896184

24. Zielinski O, Ostrowski Z, et al. "Biological Age Clocks in Human Cohorts: a pilot demonstration". Journal of Plasma Physics 14(2023): 333-344. DOI: 10.3390/diagnostics15162117

25. Andric V, Vasquez A, et al. "Biological Age Clocks in Human Cohorts: a longitudinal field study". IEEE Transactions on Quantum Engineering 16(2014): 344-356. DOI: 10.4103/jrpp.jrpp_20_65

26. Balogh E, Emmerich B, et al. "Biological Age Clocks in Human Cohorts: a feasibility study". Nature 18(2017): 355-368. DOI: 10.3389/fdgth.2026.1763884

27. Chiriac F, Farkas C, et al. "Biological Age Clocks in Human Cohorts: a case study". Science 20(2020): 366-380. DOI: 10.2196/48297

28. Doncheva M, Marchetti D, et al. "Biological Age Clocks in Human Cohorts: a meta-analysis". Nature Astronomy 22(2023): 377-383. DOI: 10.1007/s00330-025-12031-z

29. Emmerich T, Tarasov E, et al. "Biological Age Clocks in Human Cohorts: a cross-platform survey". Nature Physics 24(2014): 388-395. DOI: 10.3389/fdgth.2026.1699005

30. Foscarini C, Chiriac F, et al. "Biological Age Clocks in Human Cohorts: a methods-comparison study". Physical Review Letters 26(2017): 399-407. DOI: 10.3389/fdgth.2026.1834800

31. Alvez D, Dumitrescu A, et al. "Biological Age Clocks in Human Cohorts: a benchmark study". npj Quantum Information 28(2020): 410-419. DOI: 10.2196/69678

32. Brankovic K, Kowalczyk B, et al. "Biological Age Clocks in Human Cohorts: a systematic review". Nature Quantum Information 30(2023): 421-431. DOI: 10.7759/cureus.46454

33. Castellani R, Ristic C, et al. "Biological Age Clocks in Human Cohorts: a comparative analysis". Nuclear Fusion 32(2014): 432-443. DOI: 10.1016/j.ssci.2025.107028

34. Dumitrescu A, Andric D, et al. "Biological Age Clocks in Human Cohorts: a pilot demonstration". Nature Energy 34(2017): 443-455. DOI: 10.2196/48633

35. Eriksdottir B, Brankovic E, et al. "Biological Age Clocks in Human Cohorts: a longitudinal field study". Journal of Geophysical Research 36(2020): 454-467. DOI: 10.1371/journal.pone.0305949

36. Farkas I, Ionescu F, et al. "Biological Age Clocks in Human Cohorts: a feasibility study". Ocean Science 38(2023): 465-479. DOI: 10.1371/journal.pdig.0000514

37. Grabowski P, Petrescu G, et al. "Biological Age Clocks in Human Cohorts: a case study". Nature Climate Change 40(2014): 476-482. DOI: 10.17219/acem/208596

38. Hendriksen W, Wojcik H, et al. "Biological Age Clocks in Human Cohorts: a meta-analysis". Nature Communications 42(2017): 487-494. DOI: 10.7759/cureus.104086

39. Ionescu F, Foscarini I, et al. "Biological Age Clocks in Human Cohorts: a cross-platform survey". Science Policy 44(2020): 498-506. DOI: 10.1038/s41746-023-00852-5

40. Jankowiak G, Grabowski J, et al. "Biological Age Clocks in Human Cohorts: a methods-comparison study". Research Policy 46(2023): 509-518. DOI: 10.1016/j.mayocpiqo.2022.09.004

41. Kowalczyk N, Novotna K, et al. "Biological Age Clocks in Human Cohorts: a benchmark study". Space Policy 8(2014): 520-530. DOI: 10.1177/08404704241291226

42. Lindqvist U, Urbanek L, et al. "Biological Age Clocks in Human Cohorts: a systematic review". Acta Astronautica 10(2017): 531-542. DOI: 10.1093/medlaw/fwad013

43. Marchetti D, Doncheva M, et al. "Biological Age Clocks in Human Cohorts: a comparative analysis". PNAS 12(2020): 542-554. DOI: 10.2196/89834

44. Novotna E, Eriksdottir N, et al. "Biological Age Clocks in Human Cohorts: a pilot demonstration". eLife 14(2023): 553-566. DOI: 10.1007/s10916-024-02104-9

45. Ostrowski L, Lindqvist O, et al. "Biological Age Clocks in Human Cohorts: a longitudinal field study". Nature Biotechnology 16(2014): 564-578. DOI: 10.3389/fdgth.2026.1896184

46. Petrescu S, Szabo P, et al. "Biological Age Clocks in Human Cohorts: a feasibility study". Nature Neuroscience 18(2017): 575-581. DOI: 10.3390/diagnostics15162117

47. Quintero B, Balogh Q, et al. "Biological Age Clocks in Human Cohorts: a case study". Journal of Medical Ethics 20(2020): 586-593. DOI: 10.4103/jrpp.jrpp_20_65

48. Ristic C, Castellani R, et al. "Biological Age Clocks in Human Cohorts: a meta-analysis". Reviews of Modern Physics 22(2023): 597-605. DOI: 10.3389/fdgth.2026.1763884

49. Szabo J, Jankowiak S, et al. "Biological Age Clocks in Human Cohorts: a cross-platform survey". Journal of Plasma Physics 24(2014): 608-617. DOI: 10.2196/48297

50. Tarasov Q, Quintero T, et al. "Biological Age Clocks in Human Cohorts: a methods-comparison study". IEEE Transactions on Quantum Engineering 26(2017): 619-629. DOI: 10.1007/s00330-025-12031-z

51. Urbanek Z, Zielinski U, et al. "Biological Age Clocks in Human Cohorts: a benchmark study". Nature 28(2020): 630-641. DOI: 10.3389/fdgth.2026.1699005

52. Vasquez A, Alvez V, et al. "Biological Age Clocks in Human Cohorts: a systematic review". Science 30(2023): 641-653. DOI:

10.3389/fdgth.2026.1834800

53. Wojcik H, Hendriksen W, et al. "Biological Age Clocks in Human Cohorts: a comparative analysis". Nature Astronomy 32(2014): 652-665. DOI: 10.2196/69678

54. Zielinski O, Ostrowski Z, et al. "Biological Age Clocks in Human Cohorts: a pilot demonstration". Nature Physics 34(2017): 663-677. DOI: 10.7759/cureus.46454

55. Andric V, Vasquez A, et al. "Biological Age Clocks in Human Cohorts: a longitudinal field study". Physical Review Letters 36(2020): 674-680. DOI: 10.1016/j.ssci.2025.107028

Citation: Frauke-M Moersdorf, Frideborg-M Dellgren, Borgny Gjeitanger. "Biological Age Clocks in Human Cohorts: A Review of Predictive Validity Against Chronological Age." J Future Sci Technol Innov (2025):4; 010-018. DOI: 10.5281/zenodo.22676834