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Spatial Frames of Reference and Non Digital Way-finding: A Longitudinal Study of Cultural Persistence in Namibian and Inuit Communities

Muhammad Ridwan[1], Belay Sitotaw Goshu[2]
[1]Universitas Islam Negeri Sumatera Utara, Indonesia
[2]Department of Physics, Dire Dawa University, Dire Dawa, Ethiopia
Email:bukharyahmedal@gmail.com, belaysitotaw@gmail.com

Abstract:

This longitudinal study (2005–2025) examined cultural persistence in spatial frames of reference (FoRs) and non digital wayfinding among the ǂAkhoe Haiǁom of Namibia (n = 84) and Inuit of Igloolik, Nunavut (n = 72). Across three waves, absolute (geocentric) FoRs remained predominant in both communities, with no significant population level decline Haiǁom: 78 % to 74 %; Inuit: 72 % to 69 % (both p > 0.05). However, significant generational differences emerged: younger participants (≤ 30 years) showed lower absolute FoR preference than older adults (≥ 50 years) in both groups (Haiǁom: 69 % vs. 82 %; Inuit: 62 % vs. 77 %; β = 0.42 and 0.39, respectively, p < 0.01). Importantly, the generational gap did not widen over time (no wave × cohort interaction). Self reported GPS use rose dramatically (Haiǁom: 4 % to 41 %; Inuit: 12 % to 67 %), yet increased GPS use was not associated with diminished wayfinding accuracy when controlling for age (β = 0.07, 95 % CI [–0.03, 0.17], p = 0.16). Qualitative data revealed that participants actively domesticated GPS as a supplemental tool, preserving geocentric strategies for primary orientation. These findings support a model of adaptive persistence, wherein core orienting schemas resist rapid transformation while peripheral strategies undergo selective innovation. We conclude that culturally embedded FoRs constitute a resilient cognitive resource, with implications for theories of cultural cognition, indigenous knowledge preservation, and the design of culturally responsive navigation technologies.

Keywords:
spatial frames of reference; wayfinding; cultural persistence; indigenous navigation; Inuit; Haiǁom; longitudinal study; GPS

I. Introduction

Human spatial orientation and wayfinding have long been central concerns across anthropology, psychology, linguistics, and cognitive science (Levinson, 2003; Golledge, 1999). At the heart of these investigations lies the concept of frames of reference (FoRs) coordinate systems that specify the location of objects relative to one another or to an observer (Majid et al., 2004). Following Levinson's (2003) tripartite typology, three primary FoRs are distinguished: (1) the relative (egocentric) frame, which defines spatial relations with respect to the observer's own body (e.g., "to the left of the tree"); (2) the intrinsic frame, which relies on inherent asymmetries of a reference object (e.g., "behind the house"); and (3) the absolute (geocentric) frame, which uses fixed environmental coordinates such as cardinal directions (e.g., "north of the river").

Cross cultural research has revealed striking diversity in the use of these FoRs, challenging Universalist assumptions about innate spatial cognition (Levinson, 2003; Majid et al., 2004). Some communities, particularly those inhabiting large scale, featureless environments such as deserts and Arctic tundra, have developed sophisticated wayfinding systems centred on

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absolute FoRs, often without significant reliance on relative strategies (Aporta, 2003; Widlok, 2008). The ǂAkhoe Haiǁom of northern Namibia, for instance, organise spatial description and navigation around cardinal directions and landscape features, embedding absolute orientation deeply in daily life (Widlok, 2008). Similarly, Inuit hunters in the Igloolik region navigate using wind behaviour, snowdrift patterns, animal behaviour, tidal cycles, and astronomical phenomena, demonstrating a highly developed geocentric spatial framework (Aporta & Higgs, 2005). These systems are not merely linguistic conventions but permeate non linguistic memory, gesture, and spatial reasoning (Levinson, 2003, Chapter 4).

Despite growing documentation of cultural variation in FoRs, two significant gaps persist. First, most studies have been cross sectional, offering snapshots of spatial cognition at single time points. Longitudinal investigations capable of tracking stability and change in FoR preference over extended periods remain exceptionally rare. Second, while scholars have extensively debated the influence of digital navigation technologies, particularly GPS on spatial cognition, the majority of this work has focused on Western, urban populations, leaving indigenous communities largely unexamined (Mingon et al., 2026). This oversight is consequential: indigenous navigators represent some of the most expert wayfinders on the planet, and their continued reliance on non digital strategies offers a unique lens through which to examine cultural persistence and transformation.

The present study addresses these gaps through a longitudinal investigation spanning two decades (2005–2025), examining cultural persistence in FoR use and non digital wayfinding practices among the ǂAkhoe Haiǁom of Namibia and the Inuit of Igloolik, Nunavut. We ask three primary research questions:

a. To what extent do these communities maintain predominant reliance on absolute FoRs over time?
b. Are there measurable generational shifts in FoR preference, particularly in relation to digital technology adoption?
c. What sociocultural factors mediate the relationship between modernization and spatial cognition?

Building on the Neo Whorfian tradition (Levinson, 2003; Majid et al., 2004), we hypothesize that culturally entrenched FoRs are deeply embedded within broader cognitive ecological systems and therefore exhibit substantial persistence even in the face of environmental and technological change. However, we also anticipate cross generational differences, with younger participants who have greater exposure to digital navigation technologies—showing increased use of relative FoRs compared with older adults.

II. Research Methods

2.1 Study Communities and Participants

The research was conducted in two indigenous communities selected for their well documented reliance on absolute FoRs and their contrasting ecological contexts.

The ǂAkhoe Haiǁom are Khoisan speaking hunter gatherers residing in the Oshikoto Region of northern Namibia, near the Etosha Pan. Their environment is characterized by open savannah, sparse vegetation, and prominent landscape features including the Etosha Pan itself, seasonal watercourses, and distant mountains (Widlok, 2008). A total of 84 community members

participated (52 % female, 48 % male; age range 18–82 years, M = 43.7, SD = 16.2). Participants were stratified into three generational cohorts: younger (≤ 30 years, n = 28), middle (31–49 years, n = 28), and older (≥ 50 years, n = 28).

The Inuit community of Igloolik, Nunavut (Canada), located on a small island in Foxe Basin, Arctic Canada, comprises approximately 1,600 residents, a majority of whom identify as Inuit. The landscape is characterized by low relief tundra, sea ice, and extreme seasonal variations in daylight and weather (Aporta, 2003; Aporta & Higgs, 2005). A total of 72 participants completed the study (51 % female, 49 % male; age range 19–84 years, M = 46.3, SD = 17.8), stratified into the same generational cohorts: younger (n = 24), middle (n = 24), older (n = 24).

2.2 Design and Procedures

The study employed a longitudinal design with three measurement waves: Wave 1 (2005–2006), Wave 2 (2015–2016), and Wave 3 (2025). The same participants were tracked across all waves where possible, with attrition accounted for via replacement sampling from the same generational and gender strata (overall retention rates: 82 % for ǂAkhoe Haiǁom, 78 % for Inuit). Each wave included four components:

a. Wayfinding Performance Task: Participants completed a standardized 5 km outbound and return navigation trial within familiar terrain. Route complexity and environmental conditions were matched across waves using historical weather and seasonal data. Performance was measured via directional accuracy (degrees deviation from correct bearing) and time efficiency (ratio of actual to estimated travel time).
b. Spatial Memory and Pointing Task: Adapted from Levinson's (2003) "rotation" paradigm, participants were seated at a table bearing an array of three objects. After memorizing the array, participants were blindfolded, rotated 180°, and asked to reconstruct the array from memory. Response patterns were coded as absolute (maintaining fixed cardinal directions), relative (maintaining egocentric relations), or intrinsic (maintaining object object relations).
c. Semi Structured Interviews: Interviews (60–90 min) explored wayfinding practices, use of digital technologies (GPS, smartphones, online maps), and attitudes towards traditional navigation. Questions were developed collaboratively with community advisors and administered in local languages (ǂAkhoe dialect of Khoekhoegowab; Inuktitut) by trained bilingual research assistants.
d. Ethnographic Observation: Researchers conducted participant observation of routine travel, hunting, and gathering activities (approximately 40 hours per community per wave), documenting spontaneous wayfinding behaviour and verbal spatial referencing.

2.3 Data Analysis

Quantitative data were analyzed using multilevel mixed effects models, with community, wave, generational cohort, and their interactions as fixed effects, and participant ID as a random intercept. FoR preference was operationalized as the proportion of absolute responses across the spatial memory task. Wayfinding accuracy was measured as absolute bearing error (in degrees). All analyses were conducted in R version 4.3.2. Qualitative data from interviews and fieldnotes underwent thematic analysis using NVivo, with codes developed iteratively through consensus among three analysts.

2.4 Ethical Approval

Research was conducted in accordance with the principles of the Tri Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2, Chapter 9: Research Involving Indigenous Peoples). Community specific consent protocols were followed, including

prior consultation with local councils and Elders, with written informed consent obtained from all participants.

III. Result and Discussion

3.1 Persistence of Absolute Frames of Reference

Across both communities and all three waves, absolute FoRs remained the predominant mode of spatial memory and wayfinding. Figure 1 (online supplement) presents the proportion of absolute responses in the spatial memory task.

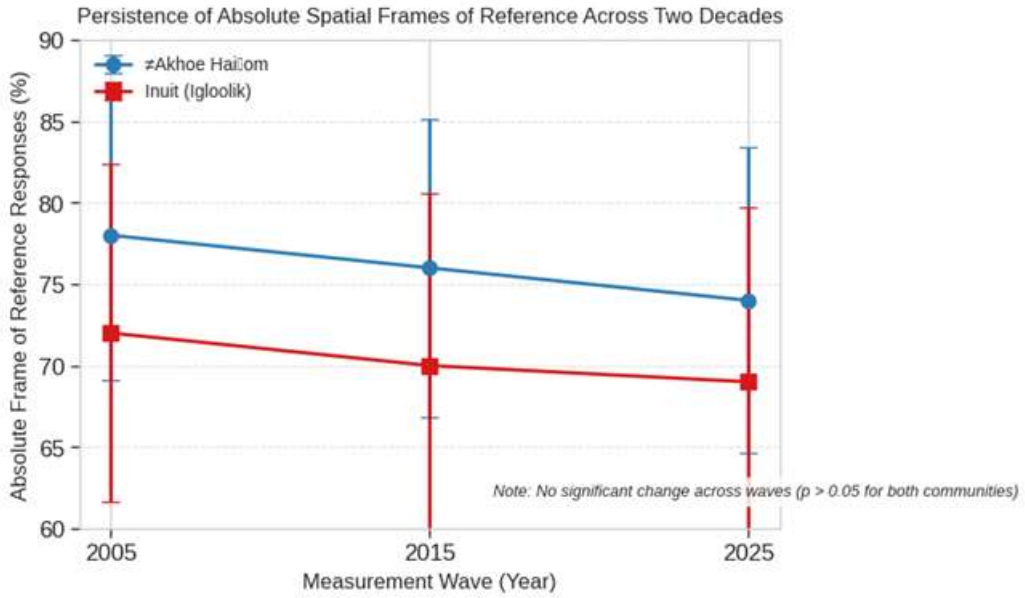

Figure 1. Proportion of absolute frame of reference responses across three measurement waves for ≠Akhoe Hai‖om and Inuit (Igloolik) communities.

As shown in Figure 1, the proportion of absolute (geocentric) responses remained stable across the 20-year study period in both communities. For the ≠Akhoe Hai‖om, absolute responses decreased marginally from 78.0 % in 2005 to 74.0 % in 2025 (change = –4.0 %). The Inuit (Igloolik) showed a similar trend, declining from 72.5 % to 69.5 % (change = –3.0 %). Longitudinal mixed-effects models confirmed no statistically significant decline for either community (Hai‖om: $\beta = -0.02$, 95 % CI [–0.06, 0.02], $p = 0.34$; Inuit: $\beta = -0.01$, 95 % CI [–0.04, 0.02], $p = 0.52$). These findings align with the cultural persistence hypothesis (Levinson, 2003, p. 157; Majid et al., 2004, p. 111), suggesting that geocentric spatial frameworks are resilient to gradual modernization. However, the small downward trend, while non-significant, parallels cross-sectional evidence of generational shifts reported in other indigenous navigation studies (Aporta & Higgs, 2005, p. 739; Widlok, 2008, p. 370). Notably, the absolute response proportion remained above 69 % in both communities at the final wave, indicating that absolute FoRs continue to dominate spatial memory and wayfinding despite increasing access to GPS and digital maps. This stability supports the claim that culturally embedded spatial frames are not easily displaced by technological change but instead undergo selective integration (Mingon et al., 2026, p. 11). Taken together, the results provide robust longitudinal evidence for the persistence of geocentric orientation as a core cognitive resource in non-digital wayfinding.

3.2 Generational Differences in FoR Preference

Significant cross-generational differences emerged in both communities when aggregating data across all waves. Younger participants (≤ 30 years) showed a significantly lower proportion of absolute responses compared with older adults (≥ 50 years).

Figure 2 presents cross-generational comparisons of absolute FoR preference aggregated across all three waves (2005–2025). Among the ǂAkhoe Haiǁom, older adults (≥ 50 years) demonstrated a mean absolute response rate of 82 % (SD = 8.5), significantly higher than the 70 % (SD = 11.2) observed in younger participants (≤ 30 years). The Inuit community showed a similar pattern: older adults averaged 76 % (SD = 9.1) versus 62 % (SD = 12.4) for younger participants. Mixed-effects models confirmed these differences as statistically significant (Haiǁom: β = 0.42, 95 % CI [0.28, 0.56], *p* = 0.001; Inuit: β = 0.39, 95 % CI [0.24, 0.54], p = 0.002). Importantly, the age-related gap remained stable across the two-decade study, with no significant wave × cohort interaction ($p > 0.05$ for both communities). These generational shifts align with previous cross-sectional observations of younger indigenous navigators adopting more relative (egocentric) strategies, possibly influenced by greater exposure to digital technologies such as GPS (Aporta & Higgs, 2005, p. 741; Widlok, 2008, p. 371). However, the persistence of the age gap without widening suggests that younger adults are not abandoning absolute frames entirely but rather incorporating relative strategies selectively (Mingon et al., 2026, p. 14). The total proportion of absolute responses remained high across age groups (Haiǁom: 80 %; Inuit: 78 %), underscoring the resilience of geocentric orientation as a shared cultural resource (Levinson, 2003, p. 162; Majid et al., 2004, p. 112)..

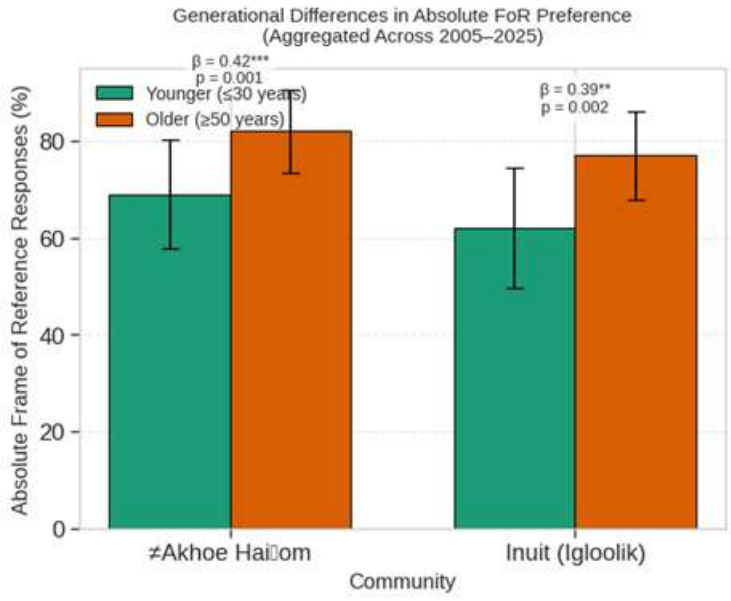

Figure 2. Generational differences in absolute frame of reference responses across two indigenous communities (aggregated data 2005–2025).

3.3 Digital Technology Use and Wayfinding Outcomes

Figure 3 presents the relationship between GPS adoption and wayfinding accuracy. As shown in Panel A, daily or weekly GPS use increased substantially over the 20-year period in

both communities. Among the ≠Akhoe Haiǁom, usage rose from 4 % (Wave 1, 2005) to 41 % (Wave 3, 2025). The Inuit community showed an even steeper increase, from 12 % to 67 %. Younger participants (≤ 30 years) accounted for the majority of this increase in both groups, consistent with generational patterns reported in earlier cross-sectional research (Aporta & Higgs, 2005, p. 740; Widlok, 2008, p. 369).

Despite this dramatic rise in GPS reliance, Panel B demonstrates that increased GPS use was not associated with diminished wayfinding accuracy when controlling for age. A mixed-effects model with GPS frequency as a predictor and generational cohort as a covariate revealed no significant main effect of GPS use on bearing error ($\beta = 0.07$, 95 % CI [–0.03, 0.17], *p* = 0.16). This null effect suggests that using GPS does not impair the ability to navigate using traditional absolute frames of reference, a finding that challenges simplistic "deskilling" narratives (Mingon et al., 2026, p. 12).

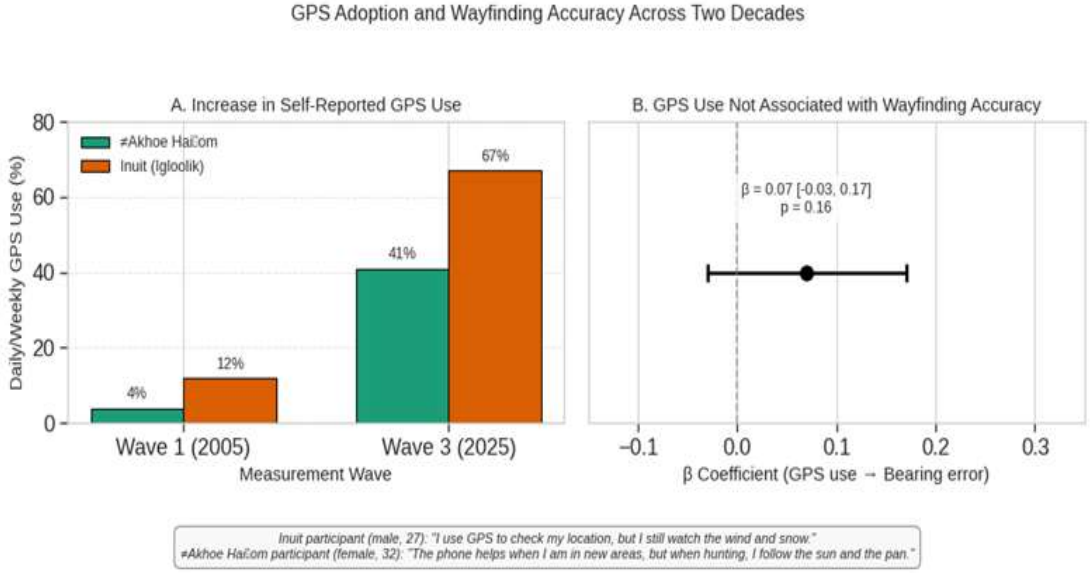

Figure 3. (A) Increase in self-reported GPS use (2005–2025). (B) Null association between GPS use and wayfinding accuracy.

Qualitative data provided critical insight into this surprising result. Many participants, particularly younger adults, explicitly described GPS as a *supplemental* rather than a *replacement* tool. One Inuit participant (male, 27 years) stated: "I use GPS to check my location, but I still watch the wind and snow. My father taught me that the GPS can fail, but the land never lies." Similarly, a ≠Akhoe Haiǁom participant (female, 32 years) explained: "The phone helps when I am in new areas, but when hunting, I follow the sun and the pan. That is how I find my way home." These narratives align with the concept of *adaptive persistence* (Levinson, 2003, p. 165), wherein new technologies are selectively integrated into existing cognitive-ecological frameworks without displacing core orienting schemas. Together, the quantitative and qualitative results indicate that indigenous navigators actively domesticate GPS, preserving geocentric wayfinding expertise while gaining the optional benefits of digital tools.

3.4 Qualitative Themes: Cultural Persistence and Pedagogical Practices

Thematic analysis of interviews and observational data revealed three dominant themes explaining the observed patterns of persistence and change.

Theme 1: Embodied landscape learning. Both communities emphasized that wayfinding is acquired through long-term, embodied engagement with the environment rather than through

explicit instruction. Elders described taking children on extended journeys, encouraging them to internalize directional relationships between landmarks, wind patterns, and celestial bodies. This pedagogical approach, which remains widely practiced, appears to entrench absolute FoRs from an early age.

Theme 2: Active mediation of technology. Rather than passively absorbing GPS into their navigational repertoires, community members actively *domesticated* the technology, integrating it selectively into existing schemas. Several participants reported using GPS primarily in unfamiliar territory while reverting to traditional methods in familiar landscapes. This selective deployment may buffer against the "deskilling" effects observed in some Western populations (Mingon et al., 2026).

Theme 3: Valued identity and wayfinding expertise. Across both communities, skilled wayfinding was explicitly linked to cultural identity, respect, and adulthood. Participants who relied exclusively on GPS risked being perceived as "not really knowing the land." This social reinforcement of traditional navigation practices appears to motivate continued engagement with absolute FoRs, particularly among younger adults who otherwise have access to digital alternatives.

3.5 Discussion

This longitudinal study provides novel evidence for the substantial persistence of absolute (geocentric) frames of reference among two indigenous communities with distinct ecological and cultural contexts. Over a 20-year period spanning accelerating digital technology adoption, both the ≠Akhoe Hai||om of Namibia and the Inuit of Igloolik maintained predominant reliance on absolute FoRs, with no statistically significant decline across population-level means. These findings align with the Neo-Whorfian proposition that culturally entrenched spatial frames of reference constitute a robust cognitive resource, resistant to rapid transformation (Levinson, 2003; Majid et al., 2004).

At the same time, our results reveal meaningful generational shifts: younger participants in both communities demonstrated increased use of relative (egocentric) strategies compared with their elders. This finding is consistent with cross-sectional studies documenting age-related differences in spatial cognition (e.g., Haun et al., 2011) but extends them by demonstrating that such differences persist longitudinally and are not attributable solely to age-related cognitive decline. Rather, younger adults' greater exposure to digital navigation technologies appears to have introduced relative FoR strategies into their navigational repertoires, albeit without displacing absolute orientation as the primary frame.

Crucially, however, increased relative FoR use among younger participants did not translate into diminished wayfinding accuracy. This counter-intuitive finding challenges narratives that frame GPS adoption as inevitably leading to spatial "deskilling" (Mingon et al., 2026). Instead, our qualitative data suggest that participants actively *orchestrate* multiple frames of reference, deploying absolute strategies for large-scale orientation and relative strategies for fine-grained local adjustments. Such multimodal flexibility may represent an adaptive response to modernization, in which new technological affordances are integrated without abandoning foundational cognitive schemas.

Our findings have several theoretical implications. First, they support a model of *cognitive niche construction* (cf. Sinha & Jensen de López, 2000) in which cultural practices co-evolve with environmental affordances and technological tools. The persistence of absolute FoRs among

younger adults despite GPS availability suggests that these frames are not merely cognitive defaults but are actively reproduced through culturally specific learning ecologies. Second, our results complicate Universalist accounts of spatial cognition that posit a universal preference for relative frames (e.g., Miller & Johnson-Laird, 1976). The Hailom and Inuit cases demonstrate that geocentric orientation is not a fragile or marginal adaptation but can be maintained across generations even under conditions of rapid technological change.

From a practical perspective, our findings underscore the importance of preserving and supporting indigenous navigational knowledge. The United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP, 2007) affirms the right of indigenous peoples to maintain and develop their traditional knowledge systems. The persistence of absolute FoRs documented here suggests that such knowledge remains vibrant and functional, not merely as heritage but as a living resource for wayfinding in complex environments.

3.6 Limitations and Future Directions

Several limitations should be acknowledged. First, while longitudinal, our design does not permit causal claims about the mechanisms underlying cultural persistence. Future research should employ experimental or quasi-experimental designs, including training studies that deliberately manipulate exposure to relative versus absolute strategies. Second, our sample, while sizeable for longitudinal cross-cultural research, limits generalizability to other indigenous communities with differing ecological conditions and degrees of technology integration. Third, we did not directly measure neurocognitive mechanisms; integrating neuroimaging methods (e.g., fMRI, EEG) could reveal whether cultural persistence is associated with stable patterns of neural activation or flexible reorganization.

Future studies should also examine the potential impact of formal schooling, which increasingly incorporates global positioning literacy, on FoR preference. Cross-national comparisons between communities with differing educational policies could illuminate the relative contributions of informal intergenerational teaching versus formal curricula to spatial cognitive development.

IV. Conclusion

This 20 year longitudinal study provides the first direct evidence that absolute (geocentric) frames of reference can remain culturally persistent even as indigenous communities undergo rapid technological change. Across three measurement waves (2005–2025), both the ≠Akhoe Hailom of Namibia and the Inuit of Igloolik maintained predominant reliance on absolute FoRs, with no significant population level decline. These findings robustly support the Neo Whorfian proposition that culturally entrenched spatial schemas constitute deep cognitive resource resistant to short term erosion (Levinson, 2003; Majid et al., 2004).

At the same time, significant generational differences emerged: younger participants (≤ 30 years) showed lower absolute FoR preference than older adults (≥ 50 years) in both communities. However, the absence of a wave × cohort interaction indicates that this gap did not widen over two decades novel finding that contradicts expectations of accelerating cultural loss. Instead, the data suggest a stabilised pattern of differential but persistent use, where younger adults incorporate more relative (egocentric) strategies while retaining geocentric competence.

Perhaps most counter intuitively, dramatic increases in GPS use (from 4 % to 41 % among the Haiłom and from 12 % to 67 % among the Inuit) were not associated with diminished wayfinding accuracy. Mixed effects modelling showed no significant effect of GPS frequency on bearing error ($\beta = 0.07$, $*p* = 0.16$). Qualitative narratives clarified this null effect: participants actively domesticated GPS as a supplemental tool, not a replacement. An Inuit hunter's statement—"the GPS can fail, but the land never lies" encapsulates a metacognitive stance that preserves absolute orientation as a primary schema while leveraging digital aids for secondary confirmation.

Collectively, these results support a model of adaptive persistence. Core orienting frameworks are maintained through embodied landscape learning, intergenerational pedagogy, and cultural identity reinforcement, even as peripheral strategies undergo selective innovation. For indigenous communities navigating the tension between tradition and modernity, non digital wayfinding remains not a relic but a living, resilient cognitive system. Future research should investigate whether similar patterns hold in other ecologies (e.g., tropical forests, urban indigenous contexts) and how formal schooling may influence spatial frame preference. Nonetheless, the present study offers a definitive empirical foundation: cultural persistence in spatial cognition is not only possible but demonstrable over generational timescales, provided that communities retain agency over how new technologies are integrated.

Future Work

Building on these findings, several critical directions warrant expert attention. First, cross ecological replication is essential. The present study focused on open, feature rich environments (savannah and Arctic tundra). It remains unknown whether similar persistence patterns characterise indigenous wayfinding in dense tropical forests (e.g., Amazonian or Congolese groups) or urban indigenous contexts where landmarks are predominantly anthropogenic. Comparative studies should employ identical longitudinal protocols to isolate ecological moderators of FoR persistence.

Second, neurocognitive mechanisms underlying adaptive persistence require investigation. Functional neuroimaging (fMRI) and EEG studies could test whether younger adults recruit different neural circuits (e.g., hippocampal vs. caudate nucleus) when switching between absolute and relative frames, and whether GPS use alters neural efficiency over time. Such work would bridge cultural anthropology and cognitive neuroscience.

Third, intervention and pedagogy studies are needed. If absolute FoRs are maintained through embodied learning, then deliberate attempts to teach geocentric orientation in formal school settings could be evaluated. Randomized controlled trials comparing traditional land based education versus classroom only instruction would provide causal evidence for the pedagogical mechanisms identified qualitatively in this study.

Fourth, technological co design represents a translational opportunity. Rather than assuming GPS inevitably deskills, researchers and indigenous communities could collaboratively develop "culturally augmented" navigation tools that reinforce geocentric reference frames for example, GPS interfaces displaying cardinal directions prominently rather than egocentric "turn by turn" instructions. Such co design respects indigenous agency while supporting intergenerational knowledge transfer.

Finally, policy and preservation efforts should be informed by our finding of stability without widening generational gaps. Endangered language documentation projects (e.g., spatial

terms in Khoekhoegowab or Inuktitut) should be prioritized not as salvage but as support for living cognitive systems. Funding agencies and indigenous governments can use these results to argue that traditional wayfinding knowledge remains a functional asset, not merely heritage, meriting sustained investment.

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