GTUD Digital Rotation — Experimental Validation Package (v6.2)

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Purpose: validate quadratic scaling $E(\Delta\theta) \propto \Delta\theta^2$ in the digital rotation experiment; provide a reproducible artifact set (data + code + hashes).

1. Scope and claims

What this package does claim:

- In a pre-registered coherent digital regime, the distance functional $E(k)=2-2C(k)$ is well-approximated by a quadratic in $\Delta\theta$ for small angles (k/n small).
- All reported results in this package are reproducible from the included raw CSV and can be verified via MD5/SHA256 hashes.
- Robustness envelopes (noise/bitflip/out-of-regime) are reported as stress-tests and clearly separated from the clean theoretical validation.

What this package does not claim:

- This does not constitute physical proof of GTUD in nature; it provides a concrete empirical path and a validated digital instantiation of $\Delta\theta^2$ scaling.
- Additive Gaussian noise on x is a robustness proxy, not a physically faithful quantum noise channel.

2. Pre-registered experiment definition

Signal mapping and distance:

In this experiment, $E(k) = 2 - 2C(k)$ is a normalized structural energy proxy derived from rotation induced correlation geometry. It is dimensionless and used to validate the GTUD required scaling $E(\Delta\theta) \propto \Delta\theta 2E$ under coherence. Physical energy units $(J)$are obtained only after introducing a scale factor κ: $EGTUD = \kappa Edigital$.

GTUD addendum (no overwrite):

• In this package, E is a normalized structural energy proxy derived from rotation-induced correlation geometry. It is dimensionless and used to validate the GTUD-required scaling under coherence:

$E(\Delta\theta) \propto (\Delta\theta)^2$.

• If a physical-energy scale is required later, introduce a single calibration factor κ:

$E_{GTUD} = \kappa \cdot E_{digital}$.

• GTUD information–energy chain (coherence-conditioned):

$I = f(\Delta\theta)$ (coherent regime)

$E = g(I)$, with the ontological constraint $E \propto I$.

Binary sequence s is mapped to a real signal x. Autocorrelation at shift k is $C(k)=\mathrm{mean}_i\, x_i\, x_{i+k}$. Distance is $E(k)=2-2C(k)$. Rotation angle is $\Delta\theta=2\pi k/n$.

Coherence filter (outcome-agnostic):

All GTUD scaling statements in this package are conditioned on the coherence filter, outside coherence, rotation does not encode stable information and quadraticity is not expected.

A sequence is accepted as "coherent" if (i) low-frequency energy ratio $\lambda \geq 0.75$ for $|f|\leq 0.08$, (ii) $|\mathrm{mean}(x)| \leq 0.10$ after normalization, (iii) sign-changes in the half-sequence are within [2, 200].

Small-angle regime and k-grid:

Primary claim is evaluated for $k \leq n/16$ ($\approx \pi/8$). One additional point at $k=n/8$ ($\approx \pi/4$) is reported as out-of-regime stress-test (higher-order terms expected).

3. Methods - exact run parameters

n=512, replicates=120, seed=42, band=0.08, lambda_threshold=0.75.

Generator: low-pass spectrum (random phases) → inverse real FFT → normalization → palindromization. Conditions include coherent_soft (clean), coherent_soft_noise_sigma{0.05,0.1,0.3}, coherent_bin (sign(x)), coherent_bin_bitflip $p\in\{0.005,0.01,0.02,0.05\}$, and two negative controls (random_bin, palindrome_bin_no_coherence).

Quadraticity metrics:

We report (A) an origin-constrained fit on the small-angle subset: $E \approx \beta\cdot\Delta\theta^2$ with R^2, and (B) a baseline-corrected origin fit for noisy conditions: $\Delta E(\Delta\theta)=E(\Delta\theta)-E(0) \approx \beta_\Delta\cdot\Delta\theta^2$ with R^2_Δ ($k>0$ only). We also report an unconstrained linear regression (slope+intercept) as a diagnostic only.

4. Core result

Condition: coherent_soft (no added noise).

Small-angle quadraticity (origin fit, $k\leq n/16$): beta_origin_mean=5.5371, R2_origin_mean=0.9758.

Diagnostic regression (with intercept): slope_mean=5.2464, intercept_mean=0.0273, R2_mean=0.9846.

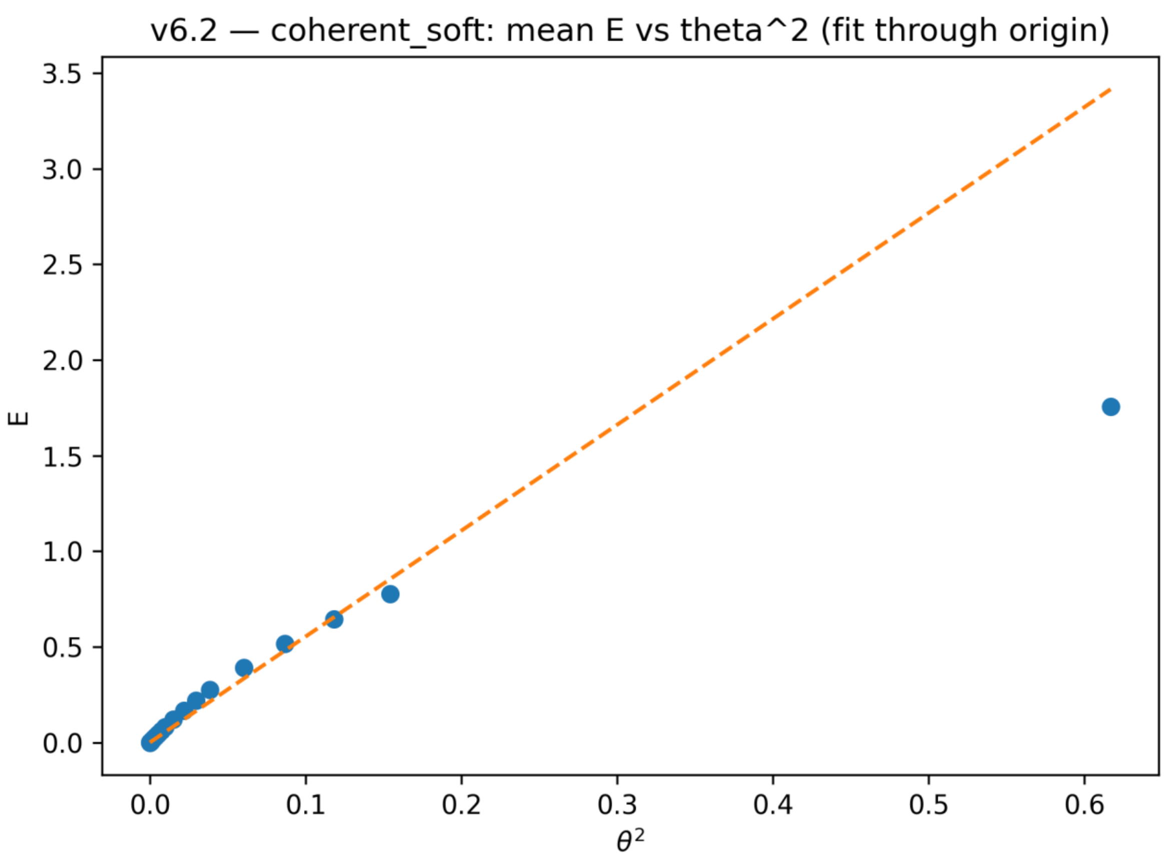
Reference points (means):

k	Δθ (rad)	C_mean	E_mean	E_std

0	0.0000	1.0000	0.0000	0.0000
32	0.3927	0.6114	0.7773	0.3645
64	0.7854	0.1211	1.7578	0.5560

Interpretation of the π/4 point: it is intentionally outside the strict small-angle regime. Deviations there are expected and do not invalidate the small-angle $\Delta\theta^2$ claim; they indicate higher-order terms / nonlinearity in C(k) for larger rotations.

Figure 1 — coherent_soft: E versus $\Delta\theta^2$ (includes π/4 out-of-regime point).



GTUD statement (within this package)	Operational definition (digital)	Pass criterion (v6.2)	Fail meaning (digital-domain)
$E(\Delta\theta) \propto (\Delta\theta)^2$ (coherent, small-angle)	$E(k)=2-2C(k)$, $\Delta\theta=2\pi k/n$	Origin-fit R^2 high in coherent_soft for $k \le n/16$	Quadratic scaling not observed in coherent regime → digital falsification of $\Delta\theta^2$ scaling in this instantiation
Coherence is	Coherence filter	Negative controls fail	If negative controls

required for stable information encoding	defined in Section 2	quadraticity (random_bin, palindrome_bin_no_coherence)	pass like coherent data → coherence filter not discriminative / measure not selective
E here is a normalized structural proxy (not Joule)	Distance functional $E(k)=2-2C(k)$	Explicit κ mapping stated: E_GTUD = κ · E_digital	If treated as Joule without calibration → units/category error
Rotation application is audit-anchored ($\Delta\theta$ not narrative)	Hash-anchored artifacts (MD5/SHA256 manifest)	verify_manifest.py matches manifest_v6_2.csv for this release	Hash mismatch → wrong data/code/version; result not validated

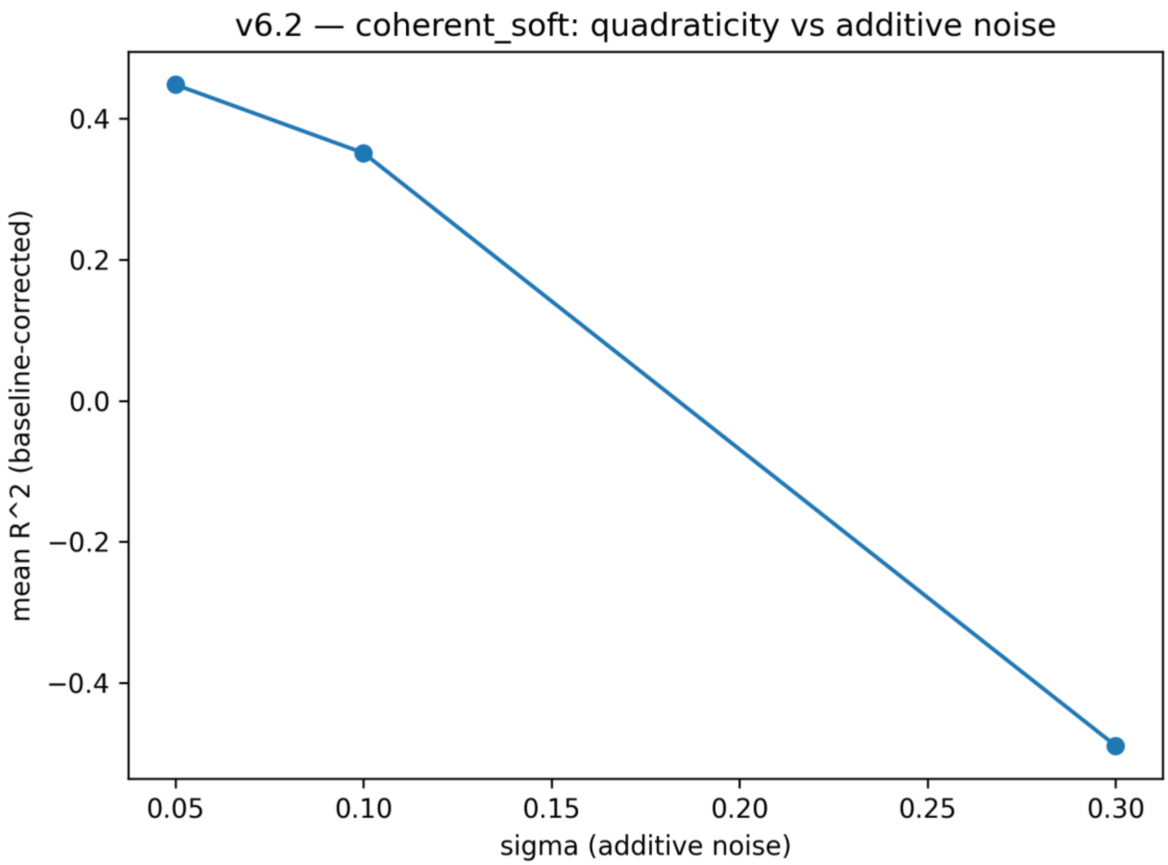
5. Stress-tests (robustness, clearly non-claim)

5.1 Additive noise (robustness proxy)

Gaussian additive noise on x is used as a process/measurement robustness proxy. Because noise makes $E(0)>0$, the baseline-corrected fit $\Delta E(\Delta\theta)=E(\Delta\theta)-E(0)$ is the relevant metric ($R^2\Delta$).

sigma	beta_origin_delta_mean	R2_origin_delta_mean	note
0.0500	9.3489	0.4482	baseline-corrected (k>0)
0.1000	9.1901	0.3513	baseline-corrected (k>0)
0.3000	9.8779	-0.4893	baseline-corrected (k>0)

Figure 4 — noise stress-test: mean $R^2\Delta$ versus sigma.



5.2 Bitflip corruption on coherent_bin

Bitflip p tests robustness for a binary channel-like corruption. Expect degradation as p increases.

p	beta_mean (diagnostic)	R2_mean	comment
0.0050	6.7983	0.8410	binary corruption envelope
0.0100	6.4816	0.8157	binary corruption envelope
0.0200	6.5037	0.7928	binary corruption envelope
0.0500	5.9273	0.7149	binary corruption envelope

5.3 Negative controls

Random and non-coherent palindromes should not show strong quadraticity in the small-angle sense. Observed:

random_bin: R2_origin_mean=-9.4549, R2_mean=0.0319.

palindrome_bin_no_coherence: R2_origin_mean=-9.1433, R2_mean=0.0376.

Figure 3 — R^2 distributions across conditions (diagnostic).

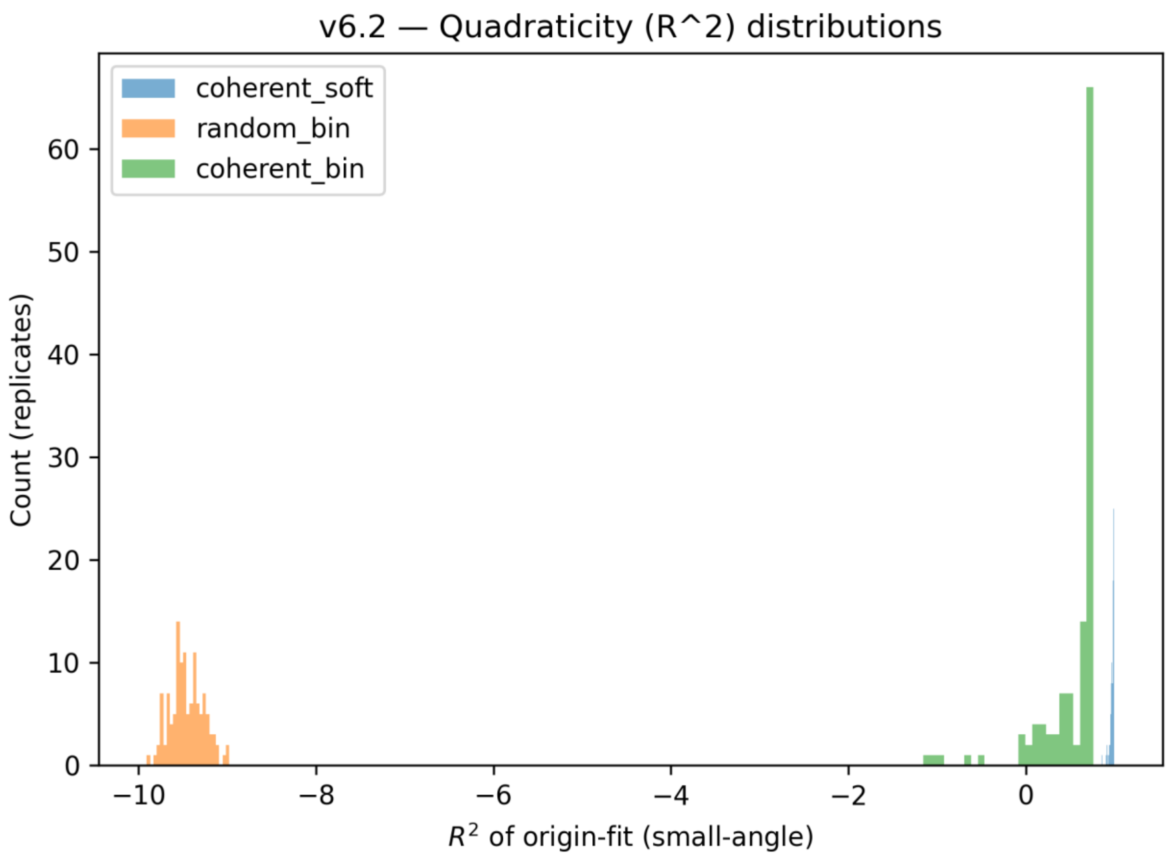
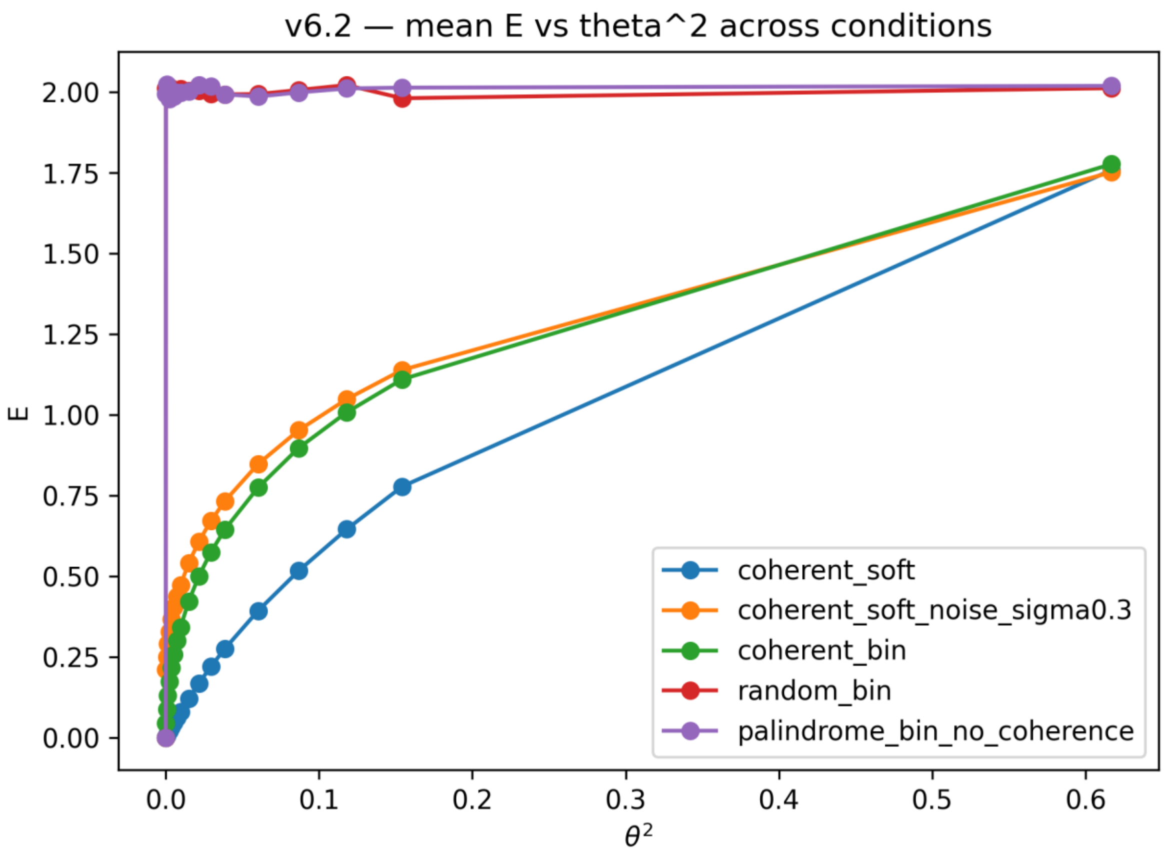


Figure 2 — comparison of conditions: mean E versus $\Delta\theta^2$.



6. What this shows, and it does not

Interpretation note (additive): E in this paper is a dimensionless structural proxy (defined as $E(k)=2-2C(k)$) used to validate the GTUD scaling form under coherence. Any Joule-scale mapping is a separate calibration step via κ (E_GTUD = κ · E_digital).

k=0 (clean) tests the core mathematical claim: $E(0)=0$ and the small-angle series around 0 is quadratic in $\Delta\theta$ under coherence. This is the strict validation anchor.

k>0 points test how long the quadratic approximation survives as $\Delta\theta$ grows. When the $\pi/4$ point deviates, that is an expected signature of leaving the Taylor-valid regime, not a failure of the $\Delta\theta^2$ mechanism.

Noise/bitflip stress-tests evaluate robustness of the measurement functional E(·) under corruption. Passing these does not "prove" quantum advantage; it indicates the digital quadratic structure is not brittle and is a plausible candidate for mapping into error-handling heuristics. For physical claims, quantum noise must be modeled as channels (dephasing, depolarizing, amplitude damping) rather than additive Gaussian noise on x.

7. Reproducibility - artifacts and hash anchors

To verify: run code/verify_manifest.py against manifests/manifest_v6_2.csv. To regenerate: run code/run_v6_2_experiment.py with the parameters listed in Section 3, then re-run make_figures.py. Regeneration produces new hashes unless you fix the full environment and RNG; therefore the manifest is the authoritative anchor for this exact release.

The manifest verifies the exact rotated-artifact outputs (hash-anchored), ensuring that $\Delta\theta$-rotation is not a narrative claim but an auditable transformation chain.

Manifest (MD5 + SHA256):

relative_path	md5	sha256
data/raw_v6_2_all_conditions.csv	cd10b6d8933147d6e8ac74f6e430537b	a159a031f6a18cf9328bc4eb034fe004a54ebf28a16fa8041dc55a8e6dd75114
data/fit_v6_2_per_replicate.csv	60dd97c3eb8a4b6a73eb5bffb3d383b8	2438447650caebf3c564aaeef604b13ccdc1b975c175360441f19994c31ff630
results/summary_by_condition_and_k.csv	92425eb3016f4fbfd3b21c519c998b7e	39755544f53d5121211248d95b7270d81c8fdcf4ee1dde9012f137ae5ce9468a
results/fit_summary_by_condition.csv	a366da2a27a664828d6704d0d8a18490	0a8393cb3d324d6b0c47396f979647422b205764456136f6583db15f504adc3f
logs/runlog_v6_2.txt	9251a451a8baf61f94a6dccaa1f48226	47d1d4e7e3c19472e06ae2274364af73bbed5bdb0534b15dd0063dc720f73dbd

Appendix A. Data files (quick dictionary)

- data/raw_v6_2_all_conditions.csv: per-replicate, per-k raw C and E values for all conditions.
- data/fit_v6_2_per_replicate.csv: per-replicate quadratic fits (origin, baseline-corrected, and diagnostic intercept fit).
- results/summary_by_condition_and_k.csv: mean/std by condition and k.
- results/fit_summary_by_condition.csv: aggregated fit metrics by condition.
- figures/*.png: figures referenced in this paper.
- manifests/manifest_v6_2.csv: hash anchors for this release.
- logs/runlog_v6_2.txt: exact command-line parameters and run metadata.