New PVT Metrics with an Improved Sensitivity to Sleep Deprivation.

Analysis from Short to Long Time Intervals.

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General context

- Interested in analyzing, studying, designing and/or assessing performances
  - … of automatic « instantaneous » alertness monitoring and drowsiness detection problems/systems
  - … by using (especially) PVTs (Psychomotor Vigilance Test)

Our PVT Protocol (22 Subjects & 3 PVTs)

- 22 Subjects (11 males, 11 females, mean 22.2y., range 19-34 years):
  - Arrival at the laboratory at 8h30, day 1.
  - Non-SDP PVT 1 : at 9h30, day 1; this is the reference “Non Sleep Deprived” PVT.
  - Go home or at work, with an actigraph and back to the laboratory at 20h30, day1.
  - SDP PVT 2 : at 02h30, during the night; this is the first Sleep Deprived PVT.
  - SDP PVT 3 : at 10h30, day 2; this is the second Sleep Deprived PVT.

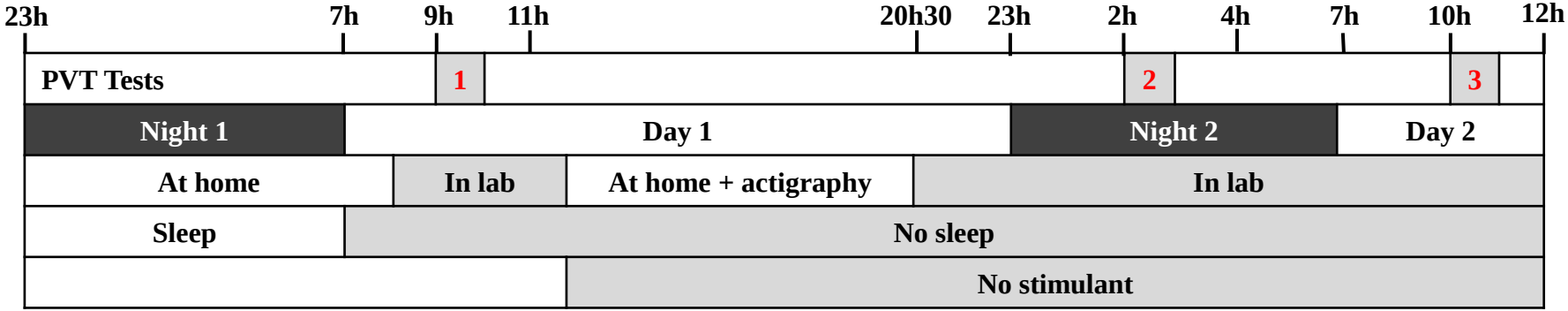
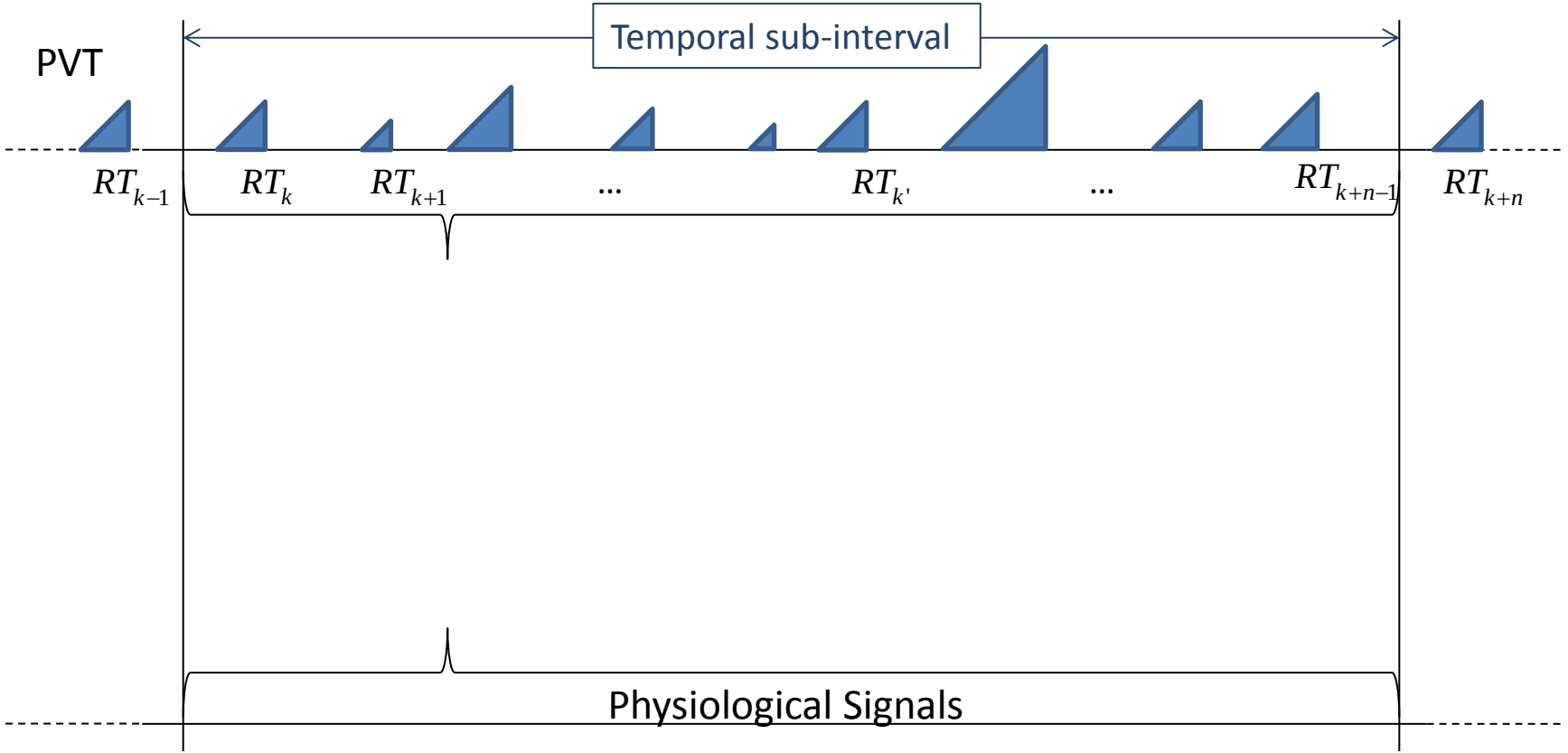


Figure adapted, with permission, from C. François & al., “Tests of a new drowsiness characterization and monitoring system based on ocular parameters”, in *Int. J. Environ. Res. Public Health*, Vol. 13, n°2, 2016, pp. 174-183

Alertness Monitoring & Drowsiness Detection



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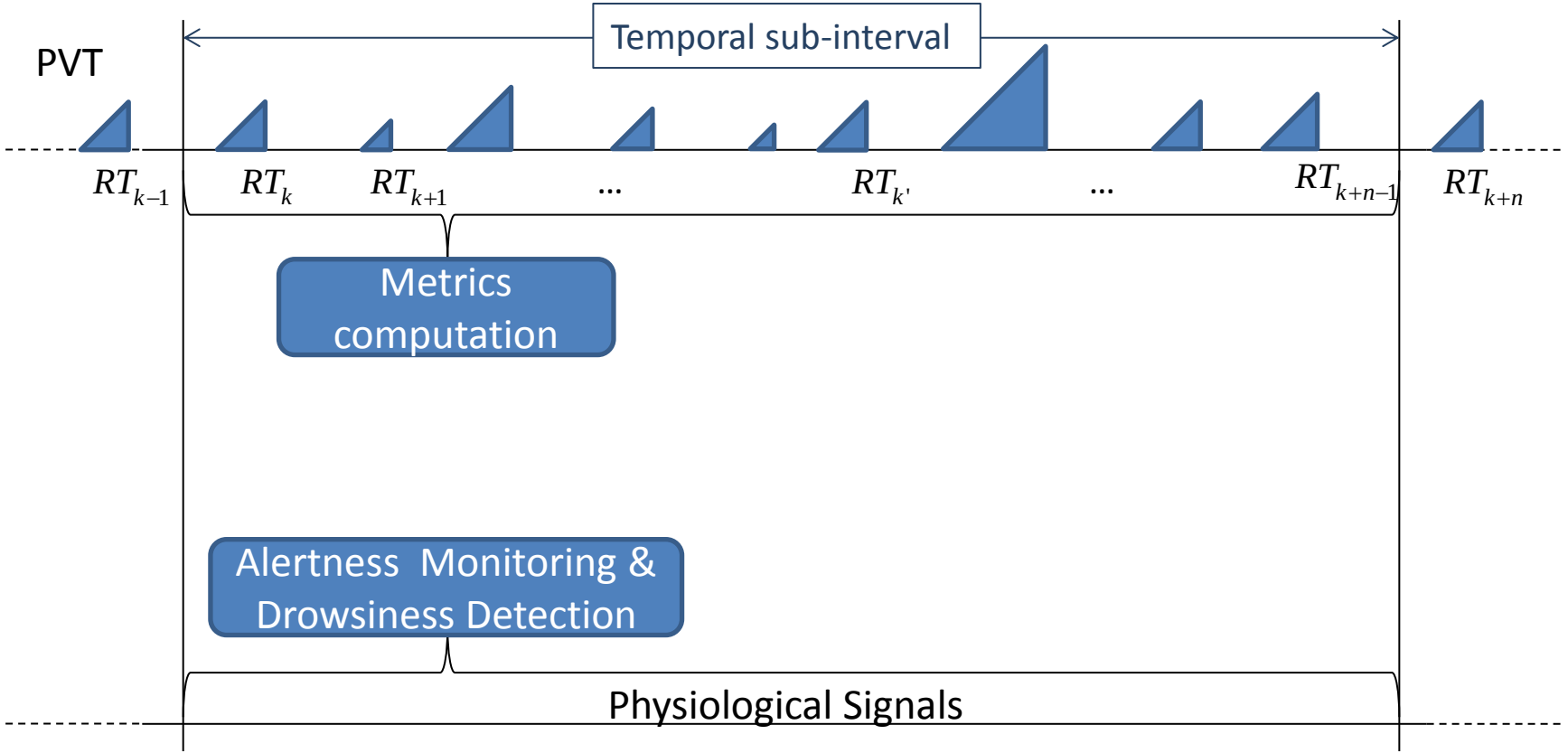

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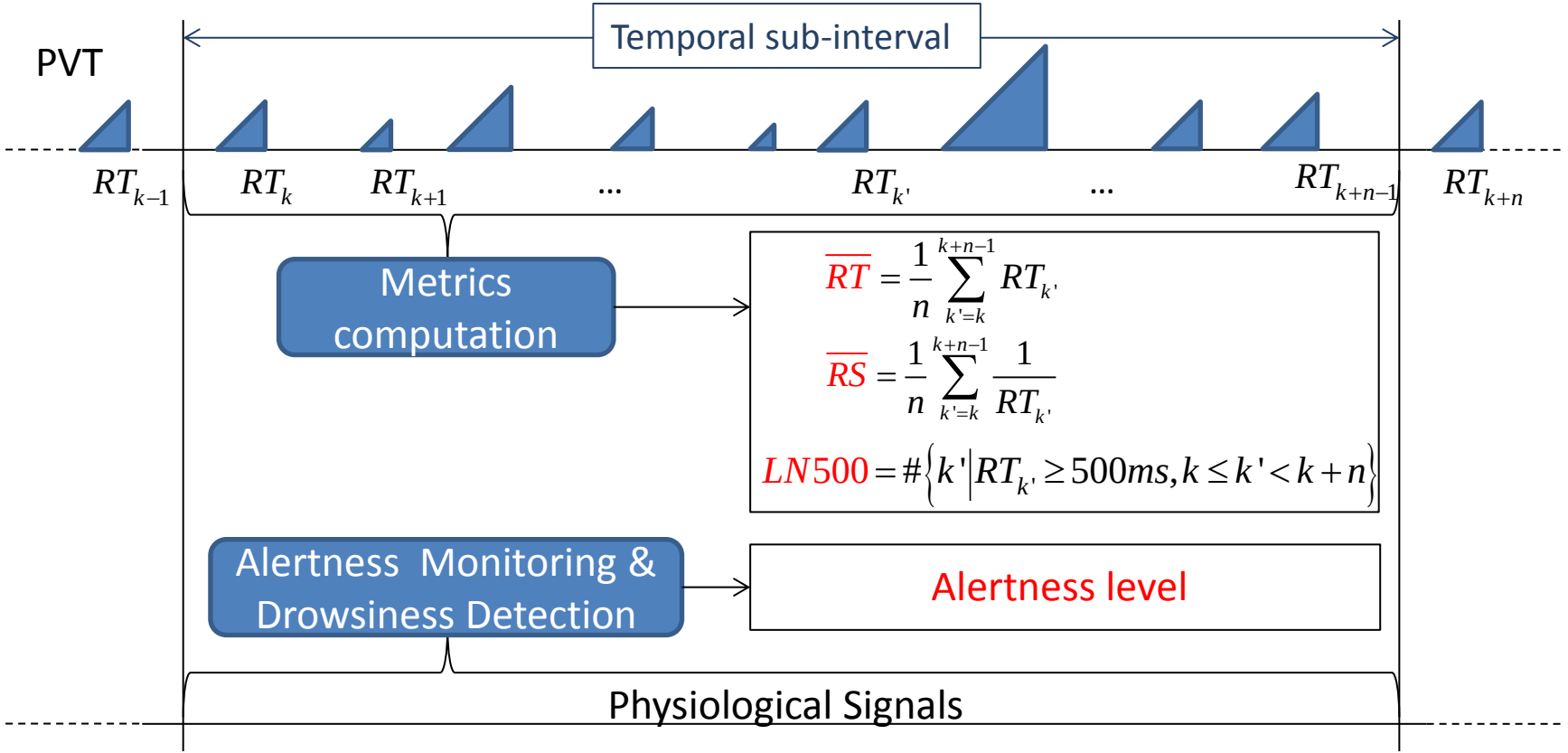

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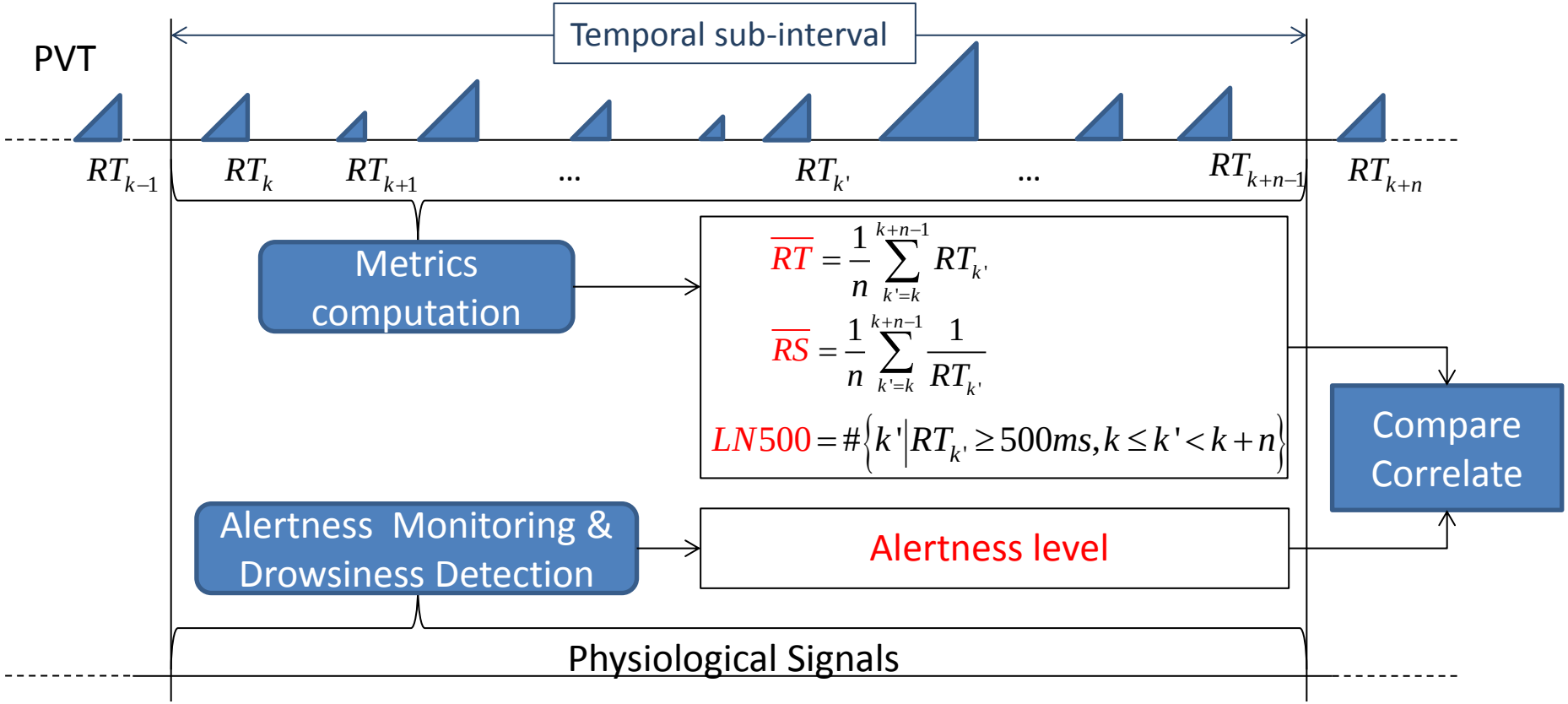

Alertness Monitoring & Drowsiness Detection

- Difficulties …
  - PVT metrics sensitivity to sleep deprivation has been demonstrated mainly when computed on the full length PVT, not on (much) shorter temporal sub-interval.
  - RT distribution (and then also any metrics distribution) are strongly dependent on the subject.
  - How is the alertness level retated to sleep deprivation?

Alertness Monitoring & Drowsiness Detection

- Difficulties …
  - PVT metrics sensitivity to sleep deprivation has been demonstrated mainly when computed on the full length PVT, not on (much) shorter temporal sub-interval.
    - Will be discussed later … stay tuned!
  - RT distribution (and then also any metrics distribution) are strongly dependent on the subject.
    - It's Now
  - How is the alertness level retated to sleep deprivation?
    - Not Today!

How to normalize metrics?

- Lapse Number
  - Use a threshold adapted to the subject; instead of 500ms for everyone.
- meanRT / meanRS
  - Not obvious at first sight
  - Could consider to apply a kind of normalizing function to RT/RS before summing or averaging

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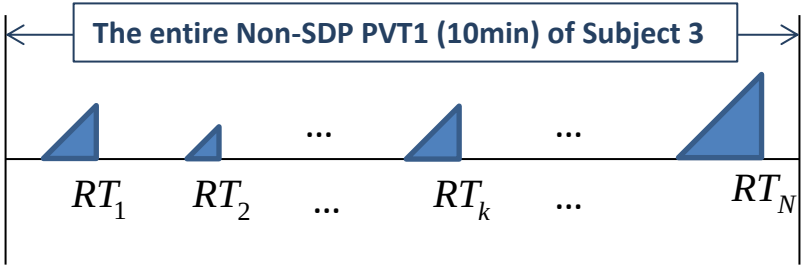
25% Quantile in the RS distrib. of PVT1



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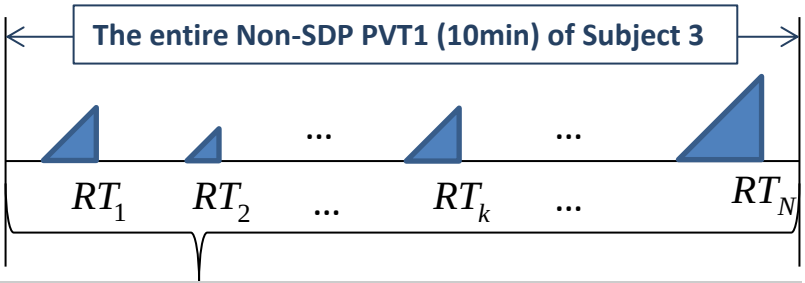

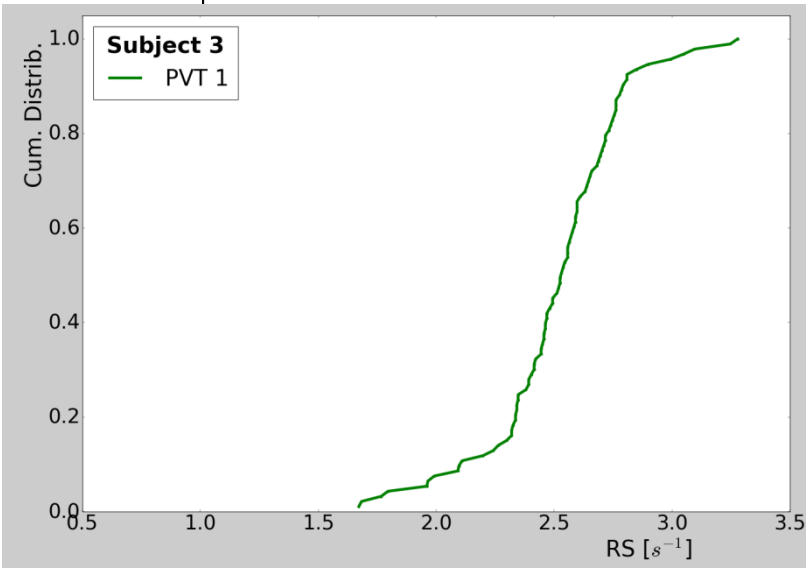

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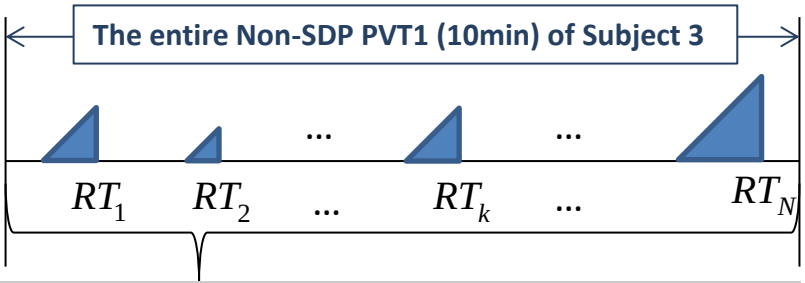

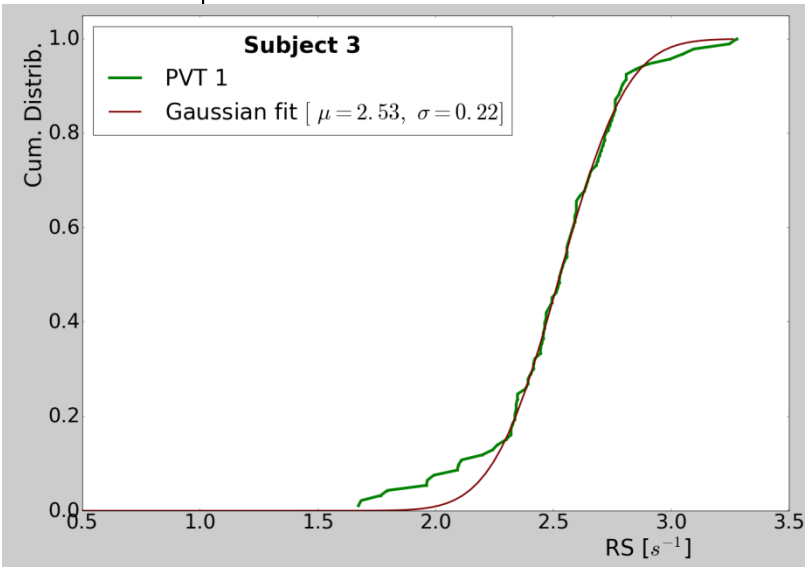

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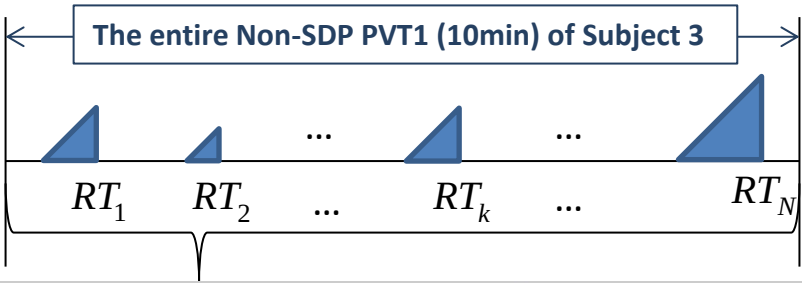

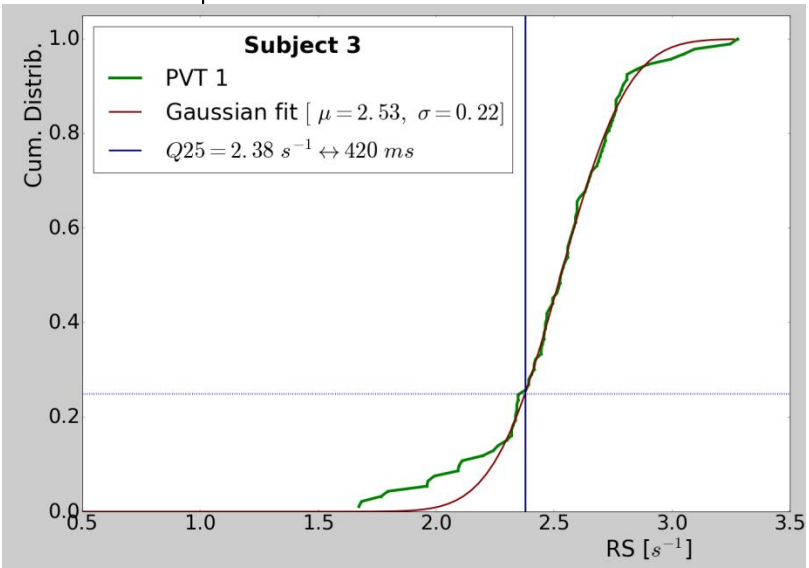

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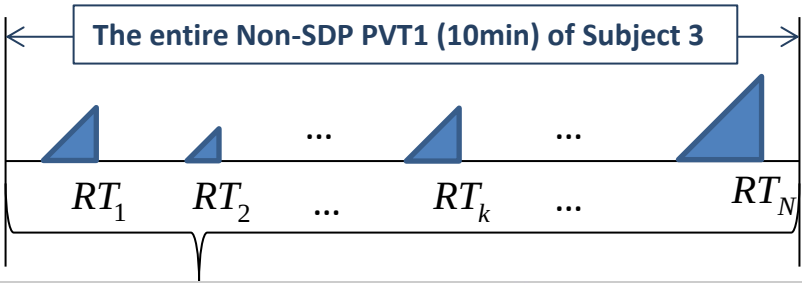
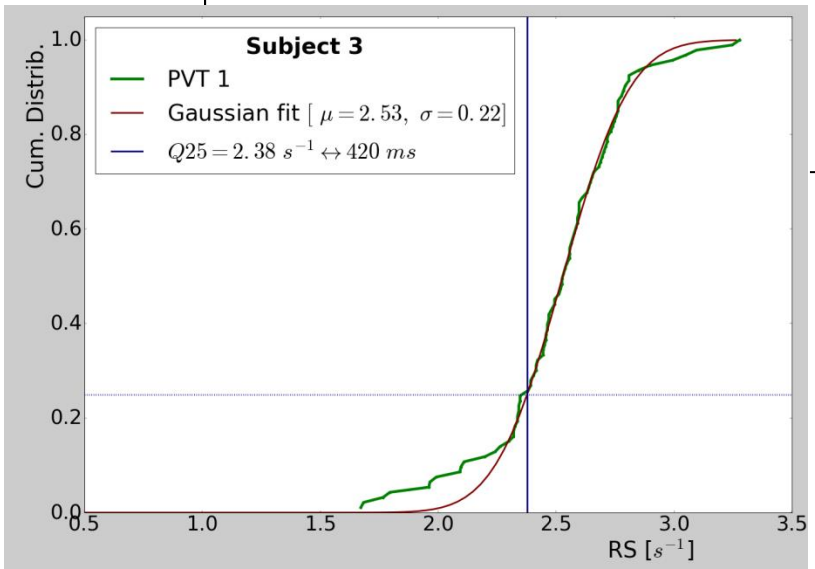
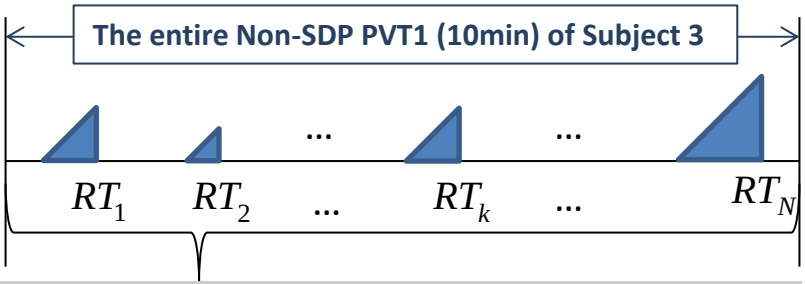
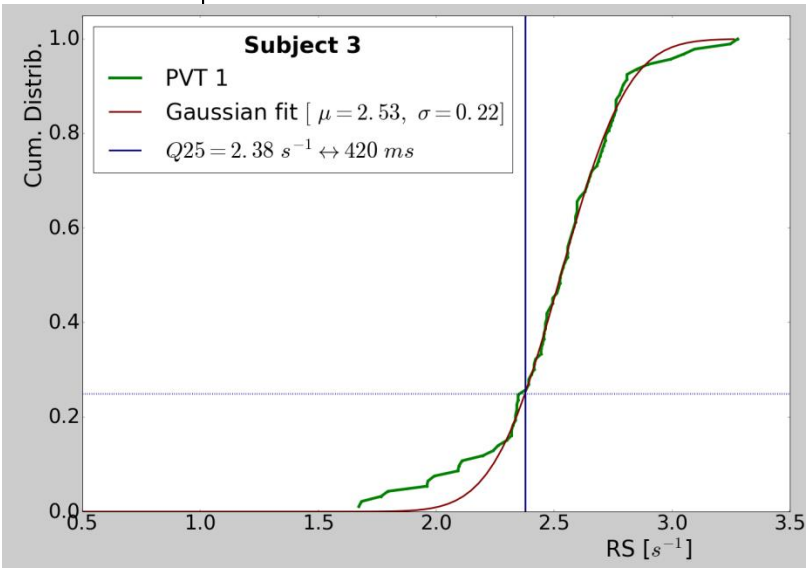


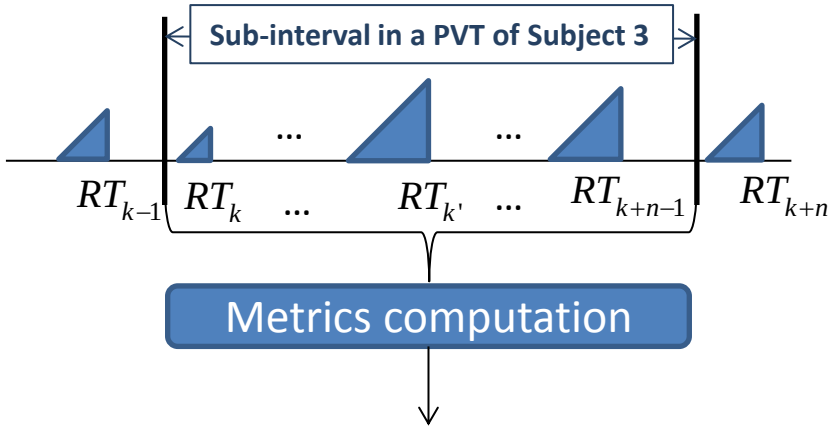


$Q25(Sbj3)$

LNQ25 : Normalized Lapse Number







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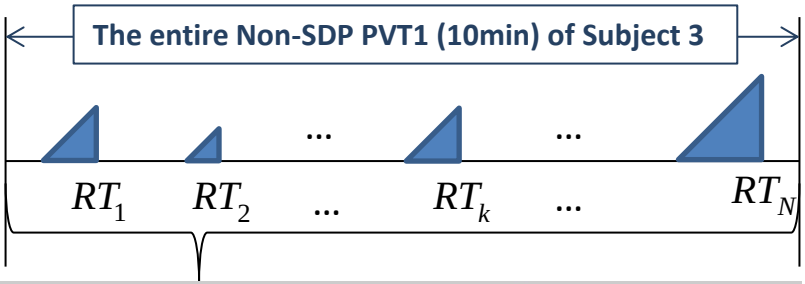

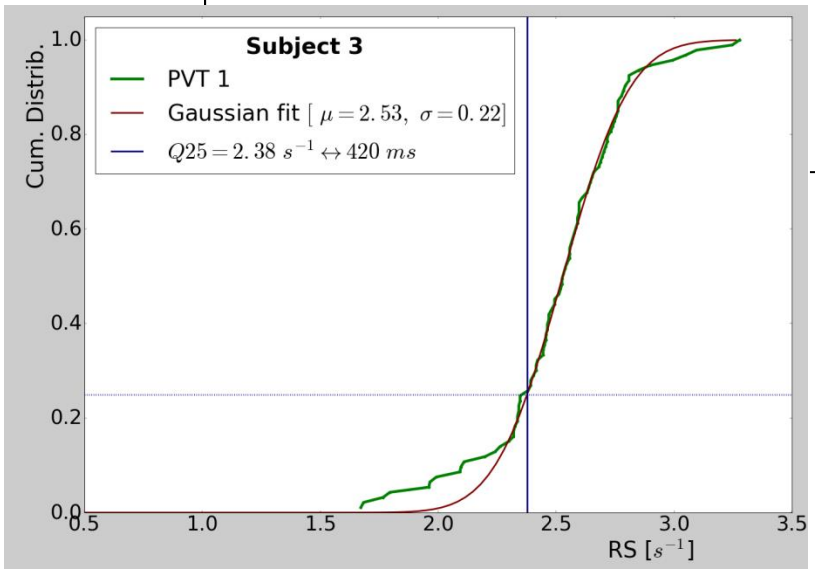

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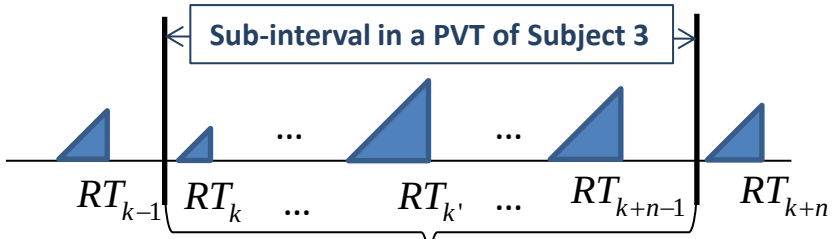

Metrics computation

$$LNQ25 = \#\left\{ k' \,\middle|\, \frac{1}{RT_{k'}} \le Q25(Sbj3), k \le k' < k+n \right\}$$

How to normalize metrics?

- Lapse Number
  - **Use the 25% quantile of the RS distribution in the Non-SDP PVT for each subject as a lapse threshold.**
- meanRT / meanRS
  - Could consider to apply a kind of normalizing function to RT/RS before summing or averaging

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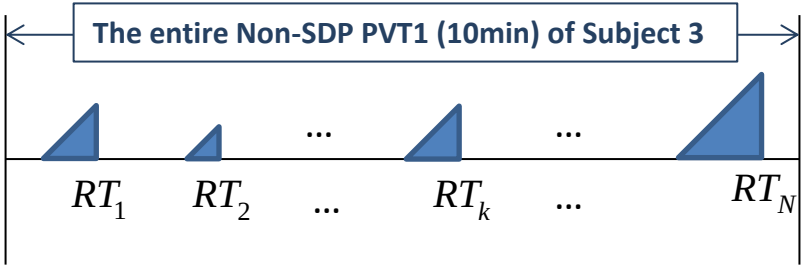
Lapse Probability



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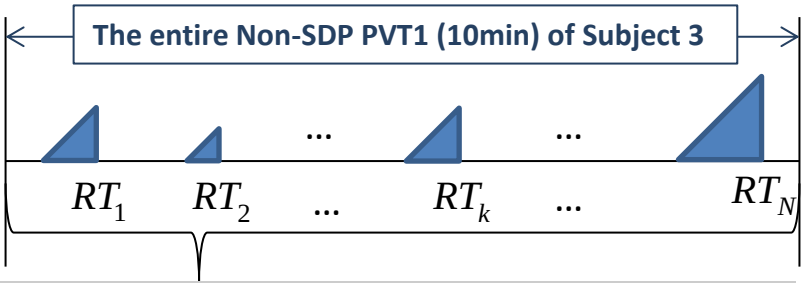

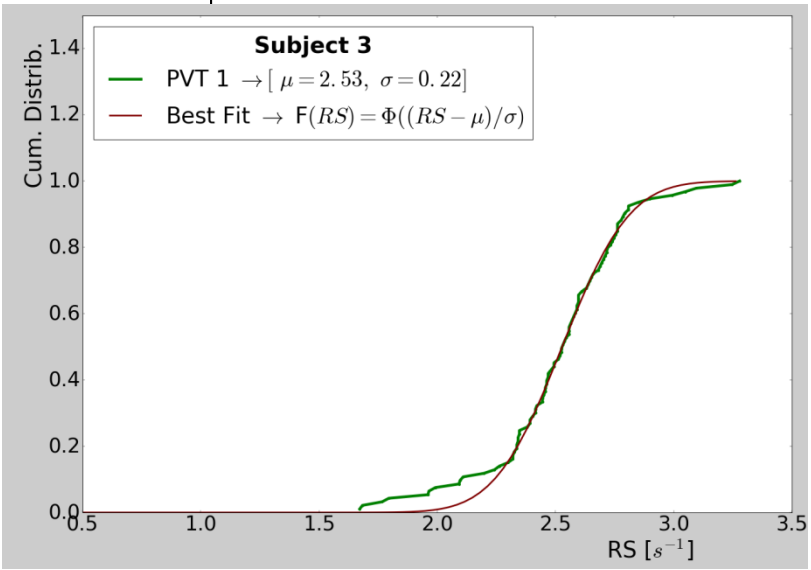

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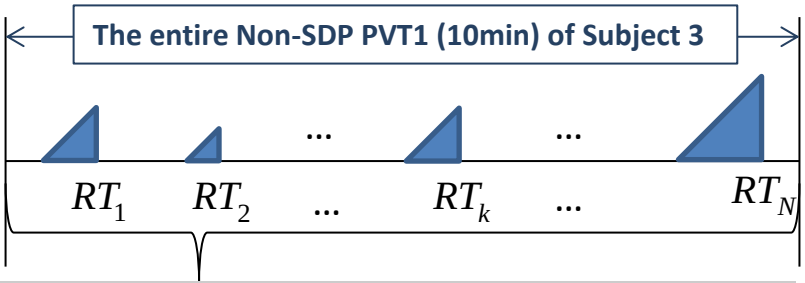
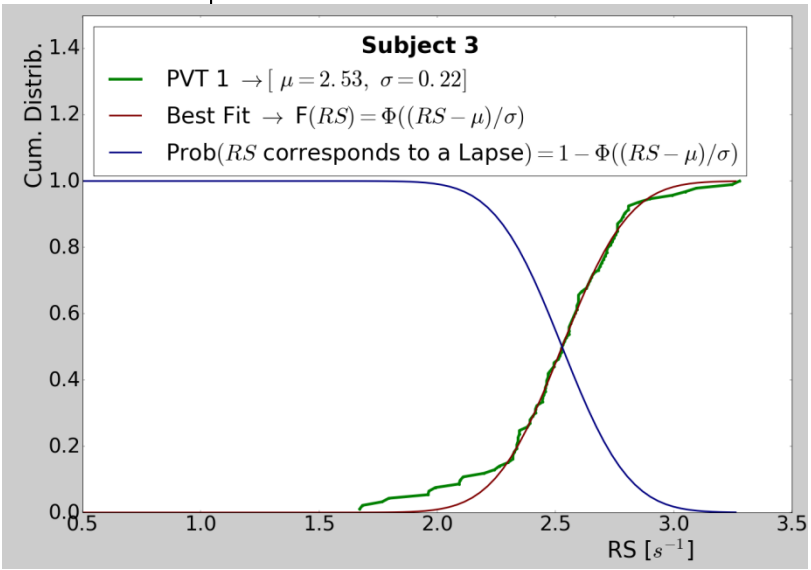
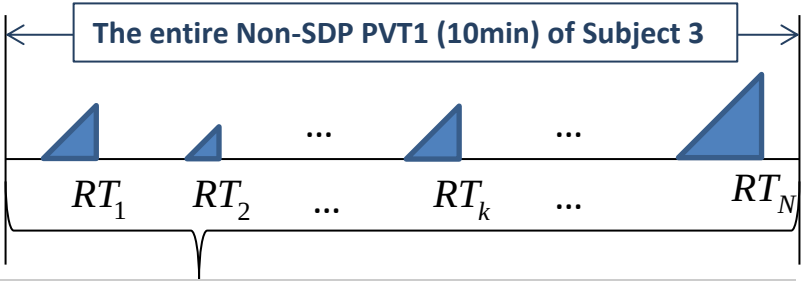
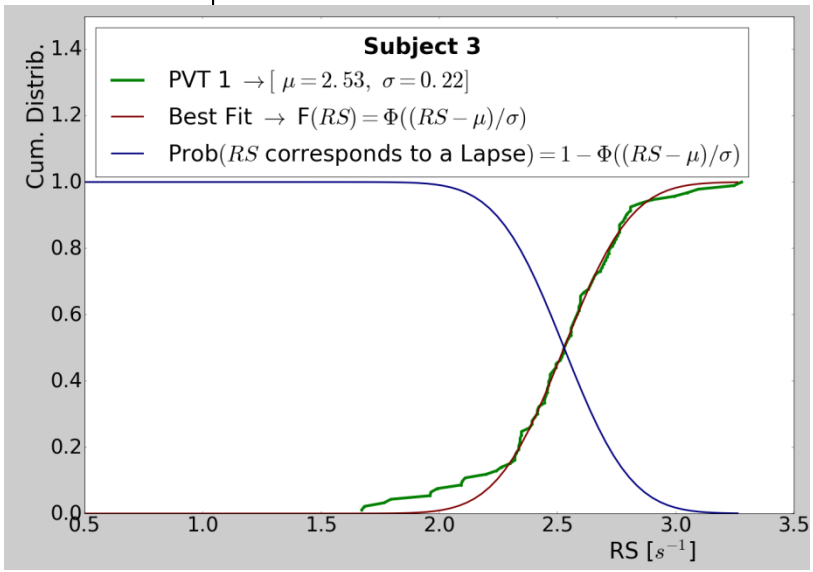


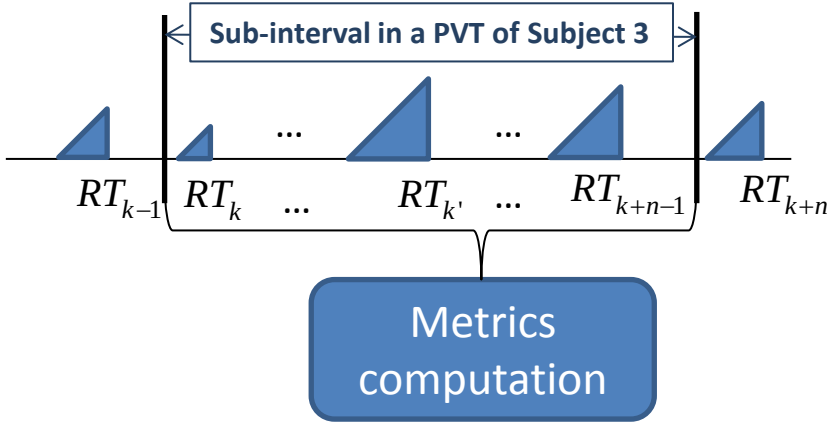


$$\mathrm{LpPr}(RS) = 1 - \Phi\left(\frac{RS-\mu}{\sigma}\right)$$

ELN: Expected Lapse Number







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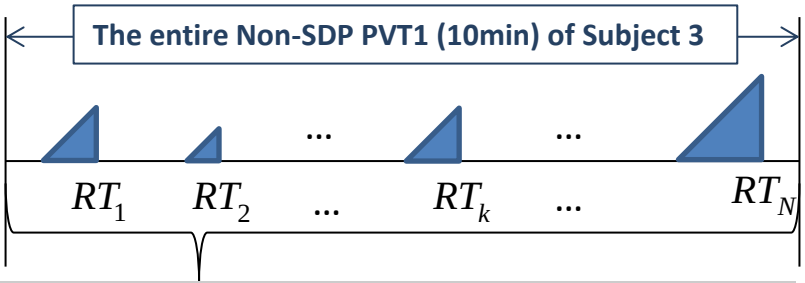

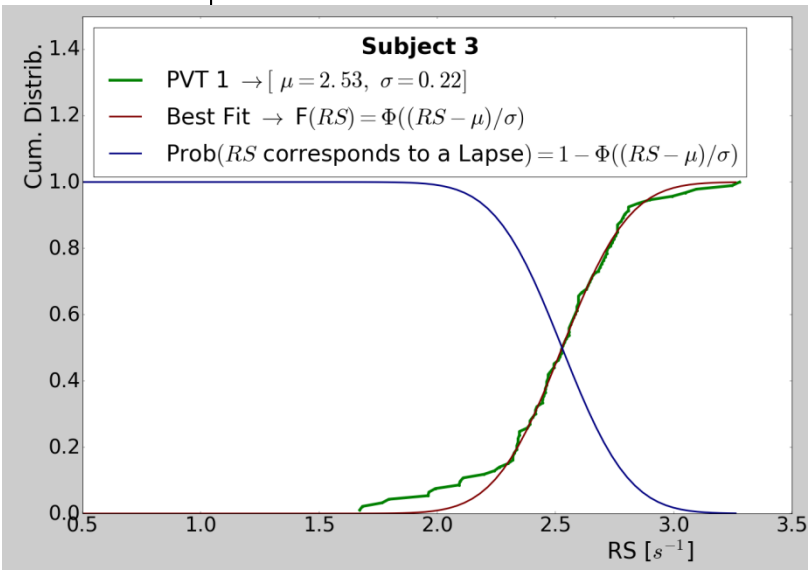

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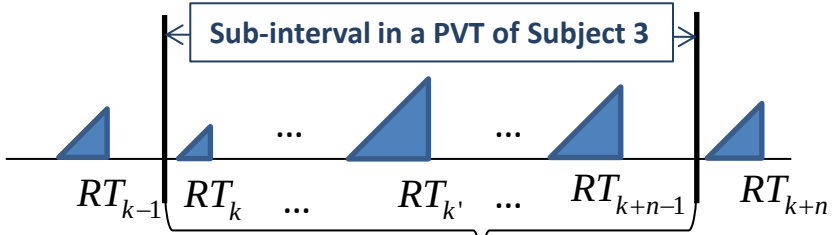


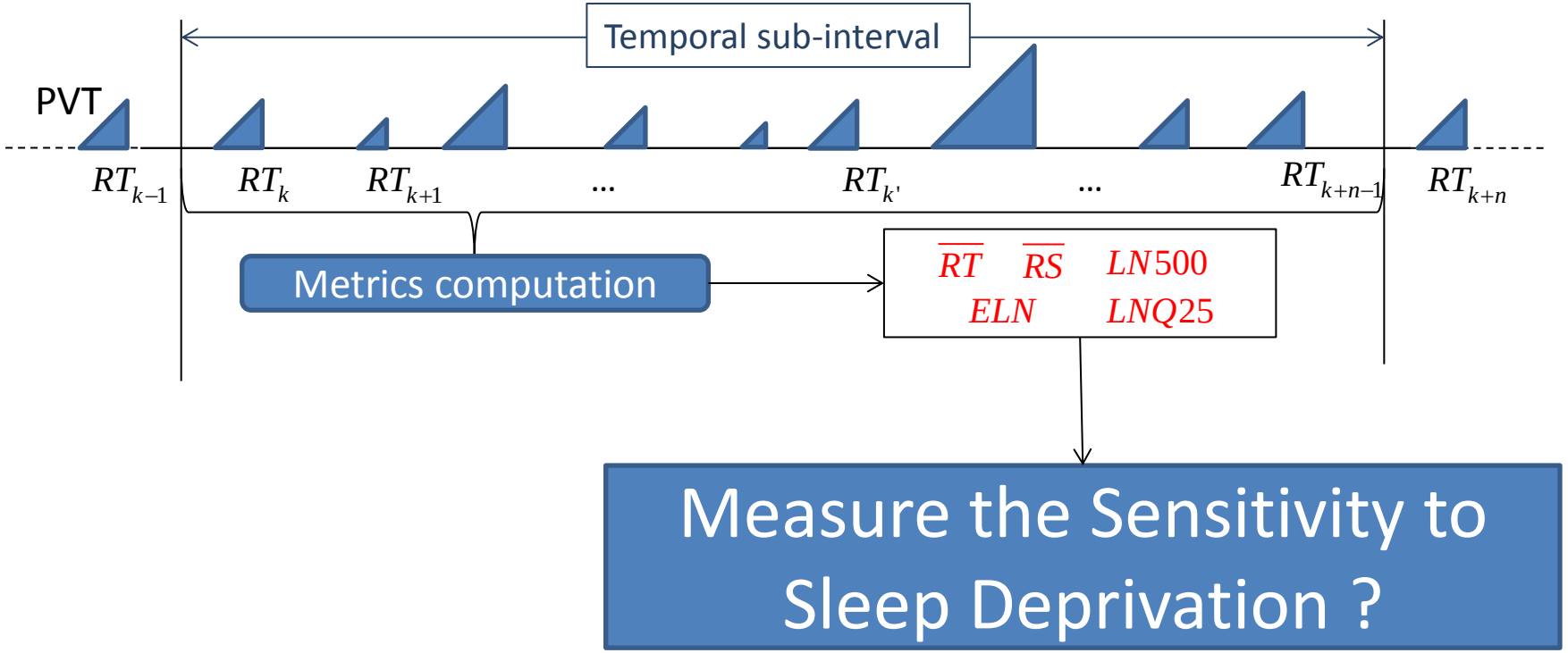
Metrics computation

$$ELN = \sum_{k'=k}^{k+n-1} \mathrm{LpPr}\left(\frac{1}{RT_{k'}}\right)$$

How to normalize metrics?

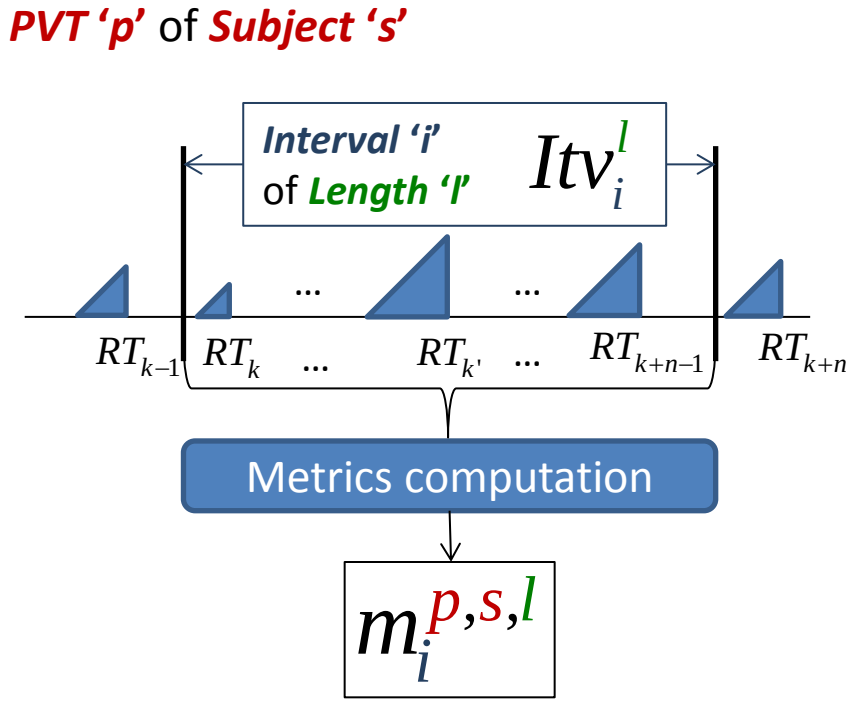
- Lapse Number
  - Use the 25% quantile of the RS distribution in the Non-SDP PVT for each subject as a lapse threshold.
- meanRT / meanRS
  - **Use an estimation of the Lapse Probability as a normalizing function for RS.**

Alertness Monitoring & Drowsiness Detection



How to measure sensitivy to Sleep Deprivation

- A metric $m_i^{p,s,l}$ is computed
- on the temporal ***Interval*** ‘***i***’
- of ***Length*** ‘***l***’
- from the ***PVT*** ‘***p***’
- of the ***Subject*** ‘***s***’



How to measure sensitivy to Sleep Deprivation

- We would like, for all ***Subject*** '***s***', ***Length*** '***l***' and interval '***i***' & '***j***',
  - $m_i^{p=(2,3),s,l}$ for the ***SDP PVT*** '***2***' or '***3***'
  - should be significantly larger than
  - $m_j^{p=1,s,l}$ for the ***Non-SDP PVT*** '***1***'

$$m_i^{p=(2,3),s,l} \overset{?}{>} m_j^{p=1,s,l}$$

How to measure sensitivy to Sleep Deprivation

- We would like, for all ***Subject*** '***s***', ***Length*** '***l***' and interval '***i***' & '***j***',
  - $\Delta m_{ij}^{p=(2,3),s,l} = (m_i^{p=(2,3),s,l} - m_j^{p=1,s,l})$
  - should be significantly positive.

$$\Delta m_{ij}^{p=(2,3),s,l} = \left(m_i^{p=(2,3),s,l} - m_j^{p=1,s,l} \right) \overset{?}{>} 0$$

How to measure sensitivy to Sleep Deprivation

- We would like, for a given interval ***Length*** '***l***',
  - The mean value $\mu_{\Delta \mathbf{m}}{}^{l}$ of the difference of metric $\Delta \mathbf{m}_{ij}{}^{p,s,l}$
    - for all ***SDP-PVT***, all ***Subjects*** and all ***Intervals*** of the given ***Length l***
  - Should be significantly positive

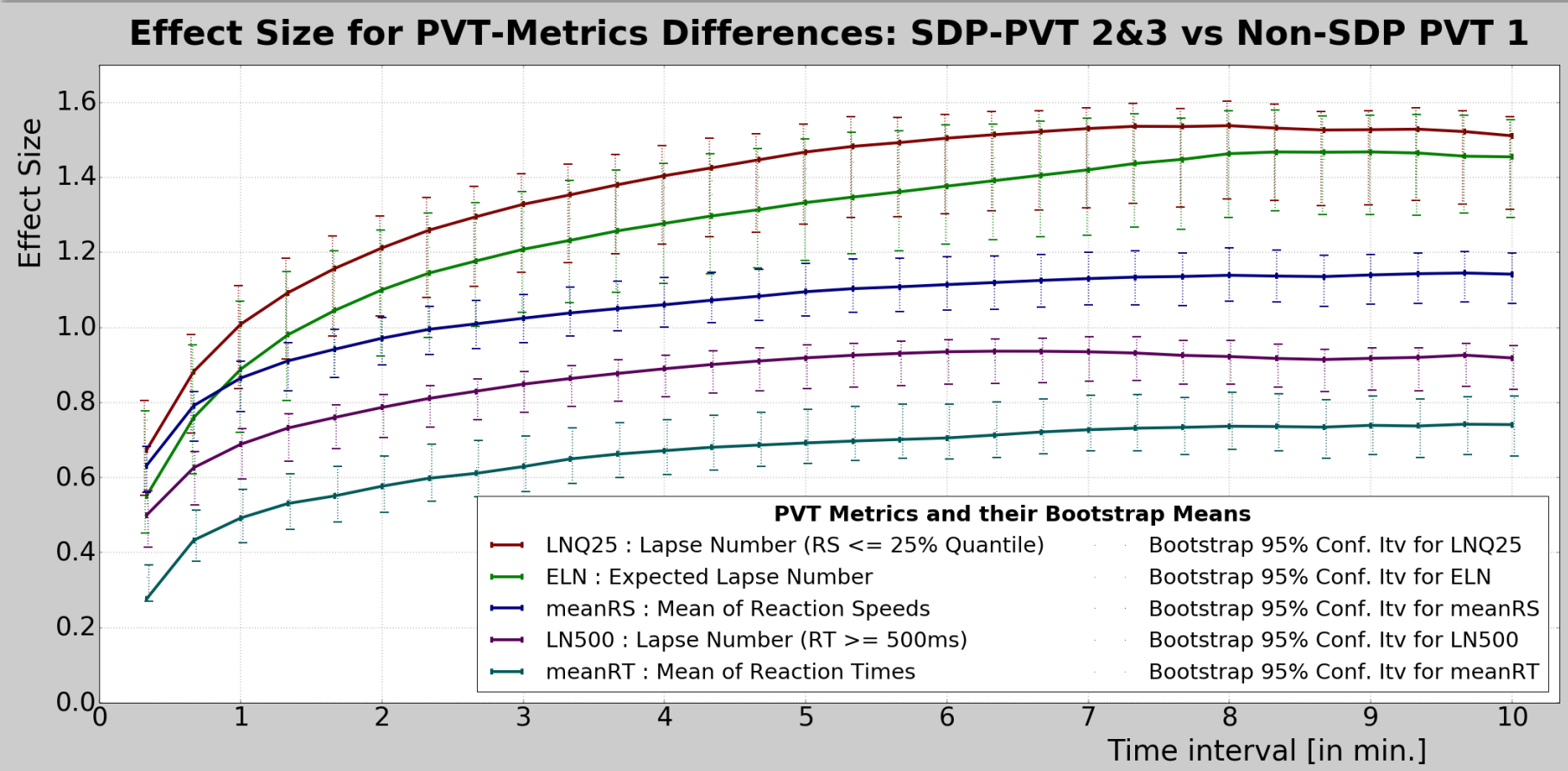
$$\mu_{\Delta m}^{l} = \underset{p,s,i,j}{\text{Mean}}\left\{\Delta m_{ij}^{p,s,l}\right\} = \frac{1}{\#_p \#_s \#_i \#_j} \sum_{p,s,i,j} \Delta m_{ij}^{p,s,l} \overset{?}{>} 0$$

How to measure sensitivy to Sleep Deprivation

- We would like, for a given interval ***Length*** '***l***',
  - the Effect Size $ES_{\Delta m}^{\ l}$,
    - which is the ratio of the mean value $\mu_{\Delta m}^{\ l}$ by the standard deviation $\sigma_{\Delta m}^{\ l}$ of the differences of metric $\Delta m_{ij}^{\ p,s,l}$
    - for all SDP-PVT, all Subjects and all Intervals of the given ***Length l***
  - Should be as large as possible

$$ES_{\Delta m}^{\ l} = \frac{\mu_{\Delta m}^{\ l}}{\sigma_{\Delta m}^{\ l}} = \frac{\underset{p,s,i,j}{\text{Mean}}\left\{\Delta m_{ij}^{\ p,s,l}\right\}}{\underset{p,s,i,j}{\text{StdDev}}\left\{\Delta m_{ij}^{\ p,s,l}\right\}} \quad \text{as large as possible}$$

Sensitivity to Sleep Deprivation of Metrics



Discussion

- We observe absolute ES values that are lower than those obtained by Basner & Dinges. The possible reasons are:
  - Our protocol slightly differs and might lower the average sleepiness in our population.
  - We use less PVTs; 3 instead of 17 (1 instead of 7 in non-SDP, and 2 instead of 10 in SDP).
- A drawback of *LNQ25*, *ELN* compared to the *meanRS* is that a reference distribution of the RS is necessary to compute them.

Discussion

- On time interval greater than 3 min, *LNQ25*, *ELN* clearly outperform the now standard *meanRS*
- On time interval greater than 2 min, the ES 95% confidence interval of *LNQ25* is greater than 1.0 and *LNQ25* is (just) greater than 1.0 after 1 minute.
- On very short interval duration (1 or 2 minutes), the covering of the confidence intervals asks us to remain cautious before drawing definitive conclusions.

Conclusions

- *LNQ25*, *ELN* and *meanRS* are the most sensitive metrics to sleep deprivation.
- PVT metrics should not be computed on time interval smaller than 2 or 3 min, for keeping the Sleep Deprivation sensitivity as large as possible.
- On our data, *LNQ25* (& *ELN)* outperform *meanRS* and should certainly be preferred, if we can accept their additional complexity.

Thank you for your attention