Esther H. D. Carlitz[1,2], Clemens Kirschbaum[2], Robert Miller[2], Joshua Rukundu[3], Titus Mukungu[3], Carolus P. van Schaik[1]

[1]Anthropological Institute and Museum, University of Zurich, Zurich, CH

[2]Department of Biopsychology, Technische Universität Dresden, Dresden, GER

[3]Chimpanzee Sanctuary & Wildlife Conservation Trust, Entebbe, UG

Correspondence: ecarlitz@janegoodall.ch

New insights into hair cortisol measurement for long-term stress monitoring in chimpanzees (*Pan troglodytes*)

Hair cortisol concentrations (HCC) are increasingly recognized as useful objective measures of long-term stress in mammals, but there is still a large gap in knowledge about the practical significance and the underlying mechanisms of confounding factors. Three problems stand out: the effect of body region, waning effects, and the reliability of HCC measures for inter-individual comparisons of stress levels. Significant differences between certain body regions (chest > shoulder blade > back = forearm) were found using hair from semi-wild and zoo living chimpanzees. However, strong correlations between regions ($r \geq 0.6$, $p < 0.001$) and results from a factor analysis suggest that the HCC values of all body regions mainly reflect one process and provide a similar biological signal. Comparisons with thermal images further suggest that intra-individual differences in skin blood flow may be the underlying mechanism of the body region effect. Concerning the waning effect, HCC along the hair shaft showed a strong, systematic decline towards distal segments in semi-wild living chimpanzees but was numerically negligible in zoo-chimpanzees. Correlations between HCC and the amount of rain, that hair was exposed to, suggest that other factors than rain are more likely to cause the strong waning effect in semi-wild living chimpanzees. Finally, we found that HCC levels were biologically meaningful at individual levels: our results revealed a strong correlation with large effect size between HCC and animal keeper-ranked stress levels for 38 chimpanzees ($pr_s = 0.6$, $p < 0.001$). In conclusion, HCC levels in chimpanzees are biologically meaningful if body region and waning effect are considered.