OJMIP> Vol.2 No.4, November 2012

OPEN ACCESS

Effectiveness of sub-maximal intermittent exercise on muscle glycogen depletion, PGC-1*α* and PDK-4 gene expression

PDF (Size:350KB) PP. 119-126 DOI: 10.4236/ojmip.2012.24017

Author(s)

Keisuke Shiose, Takuro Tobina, Yasuki Higaki, Akira Kiyonaga, Hiroaki Tanaka

ABSTRACT

Several metabolic gene expressions are regulated in concert with muscle glycogen status. We hypothesized that intermittent exercise performed at high but sub-maximal intensities with long recovery periods would induce a low glycogen state that would stimul- ate peroxisome proliferator-activated receptor-γ coa-ctivator-1α (PGC1-*α*) and pyruvate dehydrogenase kinase-4 (PDK-4) gene expression in muscle. Nine young human subjects performed two intermittent exercise sessions. One session consisted of 60 s cycling bouts at VO2max ($IE_{100\%}$), and the other session consisted of 75 s cycling bouts at 80% VO2max ($IE_{80\%}$). Twelve bouts of exercise were completed in both sessions with a 4 min rest between each bout. Muscle specimens were obtained at pre-exercise and immediately, 1.5 h and 3 h post-exercise. Muscle gly- cogen was significantly decreased after both sessions ($IE_{100\%}$, 94.1 ± 5.8 to 38.7 ± 5.5 mmol/kg w.w.; IE80%, 94.6 ± 9.1 to 53.3 ± 4.8 mmol/kg w.w.; both P < 0.05 vs pre-exercise). Muscle glycogen depletion was greater in IE100% than in IE80% (P < 0.05). PGC-1*α* and PDK- 4 mRNA expression were significantly increased after exercise in both IE100% and $IE_{80\%}$ (PGC-1*α*: ~3.7 and ~2.9-fold, respectively; PDK-4: ~11.1 and ~3.5-fold, respectively; all *P* < 0.05). Maximal PDK-4 mRNA expression after exercise was significantly greater in $IE_{100\%}$ than in $IE_{80\%}$ (*P* < 0.05). In conclusion, high but sub-maximal intermittent exercise decreased muscle glycogen and stimulated PGC-1*a* and PDK-4 mRNA expression, suggesting that increasing exercise intensity contributes to muscle glycogen depletion and PDK-4 mRNA expression in human skeletal muscle.

KEYWORDS

Intermittent Exercise; Muscle Glycogen; Peroxisome Proliferator-Activated Receptor-γ Coactivator-1α; Pyruvate Dehydrogenase Kinase-4

Cite this paper

Shiose, K. , Tobina, T. , Higaki, Y. , Kiyonaga, A. and Tanaka, H. (2012) Effectiveness of sub-maximal intermittent exercise on muscle glycogen depletion, PGC-1*α* and PDK-4 gene expression. *Open Journal of Molecular and Integrative Physiology*, 2, 119-126. doi: 10.4236/ojmip.2012.24017.

References

[1] Perry, C.G., Lally, J., Holloway, G.P., Heigenhauser, G.J., Bonen, A. and Spriet, L.L. (2010) Repeated transient mRNA bursts precede increases in transcriptional and mitochondrial proteins during training in human skeletal muscle. The Journal of Physiology, 588, 4795-4810 doi:10.1113/jphysiol.2010.199448

[2] Terada, S., Goto, M., Kato, M., Kawanaka, K., Shimokawa, T. and Tabata, I. (2002) Effects of low-intensity prolonged exercise on PGC-1 mRNA expression in rat epitrochlearis muscle. Biochemical and Biophysical Research Communications, 296, 350-354. doi:10.1016/S0006-291X(02)00881-1

[3] Pilegaard, H., Saltin, B. and Neufer, P.D. (2003) Exercise induces transient transcriptional activation of the PGC1alpha gene in human skeletal muscle. The Journal of Physiology, 546, 851-858. doi:10.1113/jphysiol.2002.034850

[4] Puigserver, P., Wu, Z., Park, C.W, Graves, R., Wright, M. and Spiegelman, B.M. (1998) A cold-inducible coactivator of nuclear receptors linked to adaptive thermogenesis. Cell, 92, 829-839. doi:10.1016/S0092-8674(00)81410-5

[5] Wu, Z., Puigserver, P., Andersson, U., Zhang, C., Adelmant, G., Mootha, V., Troy, A., Cinti, S., Lowell, B., Scarpulla, R.C. and Spiegelman, B.M. (1999) Mechanisms controlling mitochondrial biogenesis and respiration through the thermogenic coactivator PGC-1. Cell, 98, 115-124. doi:10.1016/S0092-8674(00)80611-X

[6] Wende, A.R., Schaeffer, P.J., Parker, G.J., Zechner, C., Han, D.H., Chen, M.M., Hancock, C.R., Lehman, J.J., Huss, J.M., McClain, D.A., Holloszy, J.O. and Kelly, D.P. (2007) A role for the transcriptional coactivator PGC1alpha in muscle refueling. The Journal of Biological Chemistry, 282, 36642-36651 doi:10.1074/jbc.M707006200

[7] Bowker-Kinley, M.M., Davis, W.I., Wu, P., Harris, R.A. and Popov, K.M. (1998) Evidence for existence of tissue-specific regulation of the mammalian pyruvate dehydrogenase complex. Biochemical Journal, 329, 191196.

[8] Sugden, M.C. and Holness, M.J. (2003) Recent advances in mechanisms regulating glucose oxidation at the level of the pyruvate dehydrogenase complex by PDKs. American Journal of Physiology—Endocrinology and Metabolism, 284, E855-E862.

[9] Irrcher, I., Adhihetty, P.J., Sheehan, T., Joseph, A.M. and Hood, D.A. (2003) PPARgamma coactivator-1alpha expression during thyroid hormone and contractile activityinduced mitochondrial adaptations. American Journal of Physiology—Cell Physiology, 284, C1669-C1677.

[10] Irrcher, I., Ljubicic, V., Kirwan, A.F. and Hood, D.A. (2008) AMP-activated protein kinase-regulated activation of the PGC-1alpha promoter in skeletal muscle cells. PLoS One, 3, e3614. doi:10.1371/journal.pone.0003614

[11] Polekhina, G., Gupta, A., Van Denderen, B.J., Feil, S.C., Kemp, B.E., Stapleton, D. and Parker, M.W. (2005) Structural basis for glycogen recognition by AMP-activated protein kinase. Structure, 13, 1453-1462. doi:10.1016/j.str.2005.07.008

[12] Wojtaszewski, J.F., J?rgensen, S.B., Hellsten, Y., Hardie, D.G. and Richter, E.A. (2002) Glycogen-dependent effects of 5-aminoimidazole-4-carboxamide (AICA)-riboside on AMP-activated protein kinase and glycogen synthase activities in rat skeletal muscle. Diabetes, 51, 284-292. doi:10.2337/diabetes.51.2.284

[13] Wojtaszewski, J.F., MacDonald, C., Nielsen, J.N, Hellsten, Y., Hardie, D.G., Kemp, B.E., Kiens, B. and Richter, E.A. (2003) Regulation of 5 ’ AMP-activated protein kinase activity and substrate utilization in exercising human skeletal muscle. American Journal of Physiology— Endocrinology and Metabolism, 284, E813-E822.

[14] McBride, A. and Hardie, D.G. (2009) AMP-activated protein kinase—A sensor of glycogen as well as AMP and ATP. Acta physiologica (Oxford, England), 196, 99113. doi:10.1111/j.1748-1716.2009.01975.x

[15] Pilegaard, H., Keller, C., Steensberg, A., Helge, J., Pedersen, B.K., Saltin, B. and Neufer, P.D. (2002) Influence of pre-exercise muscle glycogen content on exercise-induced transcriptional regulation of metabolic genes. The Journal of Physiology, 541, 261-271. doi:10.1113/jphysiol.2002.016832

[16] Gollnick, P.D., Piehl, K. and Saltin, B. (1974) Selective glycogen depletion pattern in human muscle fibres after exercise of varying intensity and at varying pedalling rates. The Journal of Physiology, 241, 45-57.

[17] Romijn, J.A., Coyle, E.F., Sidossis, L.S., Gastaldelli, A., Horowitz, J.F., Endert, E. and Wolfe, R.R. (1993) Regulation of endogenous fat and carbohydrate metabolism in relation to exercise intensity and duration. American Journal of Physiology, 265, E380-E391.

[18] McCartney, N., Spriet, L.L., Heigenhauser, G.F., Kowalchuk, J.M., Sutton, J.R. and Jones, N.L. (1986) Muscle power and metabolism in maximal intermittent exercise. Journal of Applied Physiology, 60, 1164-1169.

[19] Newsholme, E.A. and Start, C. (1972) Regulation in Metabolism. Wiley Interscience, New York.

[20] Chasiotis, D., Hultman, E. and Sahlin, K. (1983) Acidotic depression of cyclic AMP accumulation and phosphorylase b to a transformation in skeletal muscle of man. Journal of Applied Physiology, 335, 197-204.

[21] Sairyo, K., Ikata, T., Takai, H. and Iwanaga, K. (1993) Effect of active recovery on intracellular pH following muscle contraction, a 31P-MRS study. The Annals of Physiological Anthropology, 12, 173-179. doi:10.2114/ahs1983.12.173

[22] Shiose, K., Tobina, T., Higaki, Y., Kiyonaga, A. and Tanaka, H. (2011) An effective high-intensity intermittent exercise protocol for decreasing skeletal muscle glycogen. Japanese Journal of Physical Fitness and Sports Medicine, 60, 493-502. doi:10.7600/jspfsm.60.493

[23] Little, J.P., Safdar, A., Wilkin, G.P., Tarnopolsky, M.A. and Gibala, M.J. (2010) A practical model of low-volume high-intensity interval training induces mitochondrial biogenesis in human skeletal muscle: Potential mechanisms. Journal of Physiology, 588, 1011-1022. doi:10.1113/jphysiol.2009.181743

[24] Astrand, P.O. and Rodahl, K. (1986) Textbook of work physiology: Physiological bases of exercise. 3rd Edition, McGraw-Hill, New York. doi:10.2310/6640.2004.00030

[25] Whaley, M.H., Brubaker, P.H. and Otto, R.M., et al. (2006) ACSM ' s Guidelines for Exercise Testing and Prescription. 7th Edition, Lippincott Williams & Wilkins, Baltimore.

[26] Tobina, T., Nakashima, H., Mori, S., Abe, M., Kumahara, H., Yoshimura, E., Nishida, Y., Kiyonaga, A., Shono, N. and Tanaka, H. (2009) The utilization of a biopsy needle to obtain small muscle tissue specimens to analyze the gene and protein expression. Journal of Surgical Research, 154, 252-257. doi:10.1016/j.jss.2008.07.011

[27] Higaki, Y., Wojtaszewski, J.F., Hirshman, M.F., Withers, D., Towery, H., White, M.F. and Goodyear, L.J. (1999) Insulin receptor substrate-2 is not necessary for insulinand exercise-stimulated glucose transport in skeletal muscle. The Journal of Biological Chemistry, 274, 2079120795. doi:10.1074/jbc.274.30.20791

[28] Wang, L., Psilander, N., Tonkonogi, M., Ding, S. and Sahlin, K. (2009) Similar expression of oxidative genes after interval and continuous exercise. Medicine & Science in Sports & Exercise, 41, 2136-2144. doi:10.1249/MSS.0b013e3181abc1ec

[29] Wang, L. and Sahlin, K. (2012) The effect of continuous and interval exercise on PGC-1α and PDK4 mRNA in type I and type II fibres of human skeletal muscle. Acta physiologica (Oxford, England), 204, 525-532. doi:10.1111/j.1748-1716.2011.02354.x

[30] Akimoto, T., Pohnert, S., Li, P., Zhang, M., Gumbs, C., Rosenberg, P.B., Williams, R.S. and Yan, Z. (2005) Exercise stimulates Pgc-1alpha transcription in skeletal muscle through activation of the p38 MAPK pathway. The Journal of Biological Chemistry, 280, 19587-19593. doi:10.1074/jbc.M408862200

[31] Ojuka, E.O, Jones, T.E., Han, D., Chen, M. and Holloszy, J.O. (2003) Raising Ca2+ in L6 myotubes mimics effects of exercise on mitochondrial biogenesis in muscle. The FASEB Journal, 17, 675-681. doi:10.1096/fj.02-0951com

[32] Miura, S., Kawanaka, K., Kai, Y., Tamura, M., Goto, M., Shiuchi, T., Minokoshi, Y. and Ezaki, O. (2007) An increase in murine skeletal muscle peroxisome proliferator-activated receptor-gamma coactivator-1alpha (PGC1alpha) mRNA in response to exercise is mediated by beta-adrenergic receptor activation. Endocrinology, 148, 3441-3448. doi:10.1210/en.2006-1646

[33] Mathai, A.S., Bonen, A., Benton, C.R., Robinson, D.L. and Graham, T.E. (2008) Rapid exercise-induced changes in PGC-1alpha mRNA and protein in human skeletal muscle. Journal of Applied Physiology, 105, 1098-1105. doi:10.1152/japplphysiol.00847.2007

[34] Kiilerich, K., Gudmundsson, M., Birk, J.B, Lundby, C., Taudorf, S., Plomgaard, P., Saltin, B., Pedersen, P.A., Wojtaszewski, J.F. and Pilegaard, H. (2010) Low muscle glycogen and elevated plasma free fatty acid modify but do not prevent exercise-induced PDH activation in human skeletal muscle. Diabetes, 59, 26-32. doi:10.2337/db09-1032

[35] Wu, P., Inskeep, K., Bowker-Kinley, M.M., Popov, K.M. and Harris, R.A. (1999) Mechanism responsible for inactivation of skeletal muscle pyruvate dehydrogenase complex in starvation and diabetes. Diabetes, 48, 1593-1599. doi:10.2337/diabetes.48.8.1593

[36] Spriet, L.L., Tunstall, R.J., Watt, M.J., Mehan, K.A., Hargreaves, M. and Cameron-Smith, D. (2004) Pyruvate dehydrogenase activation and kinase expression in human skeletal muscle during fasting. Journal of Applied Physiology, 96, 2082-2087. doi:10.1152/japplphysiol.01318.2003

[37] Cluberton, L.J., McGee, S.L., Murphy, R.M. and Hargreaves, M. (2005) Effect of carbohydrate ingestion on exercise-induced alterations in metabolic gene expression. Journal of Applied Physiology, 99, 1359-1363. doi:10.1152/japplphysiol.00197.2005

[38] Handschin, C. and Spiegelman, B.M. (2008) The role of exercise and PGC1alpha in inflammation and chronic disease. Nature, 454, 463-469. doi:10.1038/nature07206