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An Analysis of Fitness Affiliated Direct-To-Consumer Genetic Tests

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AN ANALYSIS OF FITNESS AFFILIATED DIRECT-TO-CONSUMER GENETIC TESTS

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Abstract

Based on current scientific literature, Direct-to-Consumer (DTC) genetic tests for fitness capability generally lack validation and have little predictive value. We aimed to evaluate DTC genetic fitness testing companies found through Google searches. Website information including genes tested and claims made by the companies was collected. In total, thirty-one companies were evaluated. Only 8 of 31 companies identify genes being tested and of these 8, only 4 cite any scientific literature. The 6 most common genes tested (MCGT) were *ACE, ACTN3, AGT, FTO, IL6*, and *PPARG*. The 5 most common claims (MCC) were *genetically tailored nutrition, genetically tailored workout, information on injury risk, personalized fitness program,* and *response to training*. Given the lack of information provided by the companies, we cannot fully assess the claims, and can only express skepticism about the limited value of such testing as per the current scientific literature. Therefore, more research is needed to better understand genetic differences associated with athletic traits for the benefit of consumers.

An Analysis of Fitness Affiliated Direct-To-Consumer Genetic Tests

Introduction

Since the first full sequencing of the human genome in 2003, the cost of genetic sequencing has continuously decreased (Allyse, Robinson, Ferber, & Sharp, 2018). Decreasing costs have resulted in the development of a new market sector, with companies selling genetic information to consumers, using the internet as well as brick and mortar retail options (Harris, Kelly, & Wyatt, 2013). This business model is known as direct-to-consumer (DTC) genetic testing and manifests itself in a variety of products, such as ancestry testing, health testing and carrier testing (Phillips, 2016).

One increasingly common type of DTC genetic test is trait testing for fitness capability; however, genetic fitness tests generally lack validation and have little predictive value (Phillips, 2016). In the past, at-home saliva test kits were seen as commercial purchases rather than medical tests, so informed consent was not required and "there were no clear regulatory mechanisms in place to assess the analytical validity, clinical validity, and clinical utility" (Allyse et al., 2018 p. 116). Without validation studies or supporting research, DTC genetic testing companies have blazed their own trails in the scientific and business communities.

Regulation of DTC Genetic Tests

In 2010, the Food & Drug Administration (FDA) asserted its right to regulate DTC genetic tests based on the 1976 Medical Device Amendments to the Food, Drug, and Cosmetic Act. The FDA requested the companies apply for premarket approval and noted that they no longer intended to exempt such tests from more stringent regulations. In a 2017 reassessment, then FDA Commissioner Scott Gottlieb outlined a pathway for DTC genetic tests for genetic health risks to be evaluated and thus enter the marketplace upon approval, indicating the FDA's intention to differentiate between low risk, moderate risk and high risk genetic testing. According to the FDA website, DTC genetic tests relating to athletic ability are a "low risk general wellness product" and that they do not "generally" review these types of tests (https://www.fda.gov/medical-devices/vitro- diagnostics/direct-consumer-tests, date accessed: 8/11/19). As labs performing DTC genetics tests are not being held to the same analytic standards as other types of testing, the accuracy and reliability of such testing is questionable (Lippi, Favaloro, & Plebani, 2011).

Marketing of DTC Genetic Tests

The argument has been made that DTC companies manipulate "consumer identity-seeking" (Caulfield & McGuire, 2012, p. 28) by marketing the idea that a person's genetic construct determines much about them and that useful information can be drawn from their DNA. False and overstated claims are frequently made in order to lure consumers, which Murray et al (2010) describes as operating "under the protective cloak of legitimate science" (p. 459) and Spencer and Topol (2019) call "faux scientific authority" (p. 45).

The complexity of genetic testing and its implications makes it difficult to be confident consumers are fully informed of the risks, benefits, and limitations of such testing (Hawkins & Ho, 2012). Most traits are multifactorial and may be subject to epigenetic and environmental effects, so that genetic testing provides results that are difficult to interpret and easily misunderstood by consumers (Hawkins & Ho, 2012). As Harris et al states, "One common point of concern is how individuals may (mis)understand, (mis)interpret and cope with the genetic information that they are provided from genetic tests not ordered through a healthcare professional" (Harris et al., 2013, p. 277).

DTC Genetic Fitness Tests

At the beginning of 2016, Phillips reported that 246 companies were offering online DNA tests, 38 of which were categorized as testing for athletics. The first known study of these tests was published in 2013; the UK-based team of Williams, Heffernan, and Day (2014) performed internet searches to identify 22 DTC genetic fitness tests then available to the public. The genes most frequently tested for by these companies were polymorphisms in the *ACTN3* (11 of 22 companies) and *ACE* (6 of 22 companies) genes - *ACTN3* being tagged as the 'speed gene' since it had been identified as more common in speed and power sport athletes (Williams et al., 2014). Williams et al. (2014) indicated that 9 of the 22 companies they looked at did not make public information on which genetic variants were included in their test. DTC companies that do not disclose which variants they assess have been criticized because they make it impossible for academics or consumers to assess the test's validity (Webborn et al., 2015).

Webborn et al. (2015) also conducted internet searches intended to imitate what a potential consumer might do. The authors found that the relevance of genetic variants to athleticism were not made clear on the websites and required subjective interpretation (Webborn et al., 2015). The most commonly tested variant in these tests was *ACTN3 R577X,* and the second most commonly tested variant was *ACE I/D* (Webborn et al., 2015). Claims made by these companies in the study on their websites were generally lacking in scientific support (Webborn et al., 2015). Studies noted by companies that did provide citations were often not representative of the literature as a whole – something that likely would be difficult for customers to evaluate – and variant interpretation was inconsistent across different companies (Spencer & Topol, 2019).

Genes of Interest for Fitness

There are a variety of genes of interest that play a role in athleticism and DTC genetic fitness companies claim to use various subsets of these genes to predict athletic ability and individual response to exercise. Some of the most frequently cited genes that appear to impact athleticism are *ACE, ACTN3, AGT, FTO, IL6,* and *PPARG*.

ACE. The *ACE* gene plays a role in controlling blood pressure by regulating body fluid levels (Puthucheary et al., 2011). Variants in *ACE I* have been implicated in exaggerated response to training regimens, cardiac growth in response to a stimulus, and greater strength gains in response to training (Puthucheary et al., 2011). Research shows mixed results in regards to the significance of the *I* and *D* alleles. A meta analysis by Ma et al. (2013) found a significant association between the *I/I* genotype and endurance performance, whereas the *D* allele was associated with strength and performance in power related events. Other smaller studies also observed a higher frequency of the *D* allele among sprint type athletes (Nazarov et al., 2001; Papadimitriou et al, 2016). However, the long distance runners in the Nazarov et al. (2001) study had similar genotypes to controls, rather than a bias towards the *I* allele as other studies had observed. Two other studies involved elite endurance athletes from widely different sports such as cycling, gymnastics, and hockey, and found no notable differences in genotype frequencies between their athletes and controls (Rankinen et al., 2000; Taylor, Mamotte, Fallon, & Van Bockxmeer, 1999).

***ACTN3*.** The *ACTN3* gene codes for a protein found in fast-twitch muscle fibers that is activated during short bursts of activity such as sprinting (Lee, Houweling, North, & Quinlan, 2016). North et al. (1999) first reported a relationship between athletic performance and the R577X nonsense mutation, which is carried by approximately 20% of the world's population (Lee et al., 2016). It has been argued that the *R* allele is advantageous in power type events, noting that in some studies the *RR* genotype is overrepresented in power athletes whereas the *XX* genotype is associated with lower muscle strength and lower sprinting ability (Kikuchi & Nakazato, 2015).

Alfred et al. (2011) concluded that the *RR* genotype is more common among both sprint and power athletes whereas Ma et al. (2013) found a significant association between the *RR* genotype and power events only. Power athletes have also been found to be approximately 50% less likely to have the *XX* genotype (Eynon et al., 2012; Druzhevskaya, Ahmetov, Astratenkova, & Rogozkin, 2008). In contrast, evidence for the association between the *XX* genotype and endurance capability is weaker. One study found an underrepresentation of the *XX* genotype amongst endurance athletes; moreover, they found athletes with an *RR* genotype outperformed those with an *RX* genotype in an endurance exercise (Ahmetov et al., 2010). Another study also found no association between *XX* and endurance ability among Ironman Triathlon participants (Saunders et al., 2007). Based on current literature, there appears to be more consistent data supporting an association between *ACTN3* power performance and less data supporting an *XX* association with endurance performance (Guth & Roth, 2013).

AGT. According to Aleksandra et al, certain *AGT* polymorphisms are associated with sports performance. Higher levels of the angiotensin II protein, which is associated with improved power and strength performance, were seen in women who carried the *C* allele when compared to those with the *TT* genotype (Aleksandra et al., 2016). However, much of the research on*AGT* relates to hypertension, methamphetamine dependence, and coronary heart disease, and there is limited information on its relationship to athletic performance.

FTO. The *FTO* gene has been shown to relate to satiety, and appears to impact the likelihood of obesity. One study focused on a population carrying the *G* allele at a particular SNP and found it correlated with higher BMI (Scuteri, 2007). Another study surveyed children and found those with two lower risk *FTO* alleles consumed significantly less food than those with one or two higher risk alleles (Wardle, 2009). Some researchers also speculate that this gene is implicated in athleticism; however, a study by Eynon et al (2013) surveyed athletes and found the *AT* polymorphism was not associated with elite athletic status.

IL6. The interleukin-6 gene regulates the body's IL-6 levels, which are thought to be associated with inflammatory diseases (Tanaka, 2014). The frequency of the *G* allele and *GG* genotype of *IL6* have been documented to be higher among power athletes relative to controls; however, no difference in allele frequency has been seen between endurance athletes and controls (Ruiz et al., 2010). Eynon et al. (2011a) analyzed *IL6* genotypes and found no statistically significant differences amongst any groups and therefore stressed the need for replication studies to fully understand any potential associations between specific alleles and athletic status or performance.

PPARG. The *PPARG* gene belongs to a family of Peroxisome Proliferator-Activated Receptor (PPAR) genes, which have been shown to have an association with certain fitness phenotypes (Leońska-Duniec, Ahmetov, & Zmijewski, 2016). The *PPARG Alanine (Ala)* allele, compared to the *Proline (Pro)* allele, was significantly more common in power athletes relative to endurance athletes (Drozdovska, Dosenko, Ahmetov, & Ilyin, 2013). Leońska-Duniec et al. (2016) found that those with the *ProPro* genotype experienced a greater reduction in body fat following an aerobic training program relative to *Ala* carriers; suggesting the *Ala* genotype may weaken the beneficial effects of such a training program. The *Ala* carriers, on the other hand, seemed to benefit more from resistance style training (Leońska-Duniec et al., 2016).

Opinions of Genetic Fitness Testing

With no regulation of DTC genetic fitness tests to provide quality assurance, expert opinion on current genotype testing practices for fitness associated phenotypes is particularly valuable. Mattsson, Wheeler, Waggott, Caleshu, and Ashley (2016) state that research supporting genetic testing for sports is based on too small a sample size: study sizes need to be increased and studies replicated so that what is reported is not overestimated. Given small homogenous cohorts, the results cannot be extrapolated to the general population and should not be utilized in such a way (Mattsson et al., 2016). Genome wide association studies (GWAS) looking for single nucleotide polymorphisms, or SNPs, for athletic ability typically have small sample sizes (N=100-200) as compared to GWAS studies looking into medical conditions such as Alzheimer's, which inherently limits the application to the general population (Eynon, Morán, Birk, & Lucia, 2011b). Moreover, general research in the field has been performed on Caucasian/European participants, thus making the extrapolation of the results more difficult for the general population (Vlahovich et al., 2017b).

Other experts stress that the performance of an athlete is not based solely on his/her genetics; rather, a multitude of genetic and non-genetic factors that make up ability (Brooks &

Tarini, 2011). In one study, one hundred twenty known genetic alleles that play a role in athletic performance were categorized into 77 endurance-related genetic markers and 43 power/strength-related genetic markers (Ahmetov & Fedotovskaya, 2015). Only 9% of the total markers showed a genotype-phenotype relationship with athletic status in three or more studies analyzed (Ahmetov & Fedotovskaya, 2015). Whatever benefit there may be from understanding this complex genetic information via DTC genetic fitness testing, the lack of sufficient genetic counseling available to consumers may present a further limitation (Vlahovich, Fricker, Brown, & Hughes, 2017a; Webborn et al., 2015).

In regards to the *ACTN3* genotype, Webborn et al. (2015) state, "Contribution to the degree of inter-individual variability in sprinting performance is trivial" (p. 1490) which may result in, as Murray et al. (2010) says, manipulation and subjected misuse of scientific information. Caulfield (2011) emphatically states that even though there is an underlying basis for testing for *ACTN3* and fast-twitch muscle fibers, "It is wrong to imply that it is a test for athletic ability, a complex, socially constructed and multi-factorial concept, or that it can provide anything close to a definitive conclusion about future speed abilities" (p. 3). As Caulfield (2011) notes, there will be athletes in the Olympics without the R577 variant and there will be people with the R577 variant watching the Olympics from home.

Methods

In October 2019, two iterations of an internet search were conducted to identify commercially available fitness and exercise related genetic tests. To mimic what a potential consumer could find if interested in DTC genetic fitness testing, four English language internet search terms were typed into the internet browser www.google.com: GENETIC, TEST, FITNESS, DNA. The websites found in the first ten pages of each search were recorded.

Each website was examined for the following information, if available: website address, name of DTC company, name of the genetic fitness test, genes identified, scientific articles cited, general marketing claims, if an FAQ section was present, cost of testing, if previous genetic testing results could be imported, and if the company offered nutrition specific genetic testing. Data points from each DTC company were entered into a spreadsheet for analysis. Thirty-four companies were identified in total, including 3 companies that did not ship to the United States and were subsequently excluded from analyses, giving a total of 31 companies assessed. Descriptive statistics were employed to examine the type, frequency and evidentiary support of claims on behalf of the DTC genetic fitness testing products, and (where possible) the genes included for testing.

Results

In total, 31 companies were identified with websites that sold DTC genetic fitness tests in the U.S. (Table 1). Of the 31 websites, 8 identified the genes tested, noted in bold. One hundred forty-five unique genes were included in one or more of these 8 tests (Table 2). The genes *ACE* (5), *ACTN3* (7), *AGT* (6), *FTO* (7), *IL6* (6), and *PPARG* (6) were the 6 most common genes tested (MCGT) (Figure 1). Seven websites cited scientific literature while 24 did not (Figure 2). Of the 7 websites, 2 websites had 2-5 articles, 1 website had 6-10 articles, and 4 websites had 11+articles. Only 4 of the 8 websites that identified genes cited any scientific literature (Table 1).

The 5 most common claims (MCC), seen in at least one third of the websites, were *genetically tailored nutrition* (12), *genetically tailored workout* (17), *information on injury risk*

(14), *personalized fitness program* (13), and *response to training* (11) (Figure 3). The cost of DTC genetic fitness tests was an average of $182 and ranged from $20 to $399 (Figure 4). Two companies with very low cost testing, Xcode and FoundMyFitness ($20 and $25 respectively), required consumers to upload their own genetic data file from companies such as 23andme. Four websites did not list a price for their test.

Table 1 - DTC Genetic Fitness Testing Companies Assessed

DTC Company	Website	Test Name	Genes Identified? (Y/N)	Literature Identified? (Y/N)
Advanced Genomic Solutions	ags-testing-kits.myshopify.com	NutraFit Health & Wellness Genetic Test	N	N
CALIGENIX	caligenix.com	Sports Nutrition	N	N
Circle DNA	circledna.com	Vital DNA Test	N	N
DNAFit	**dnafit.com/us**	**Health Fit**	**Y**	**Y**
dnaPower	dnapower.com	fitPower	N	N
DNA Code	dnacode.com	Fitness & Nutrition	N	N
Dnomium	dnomium.com	Fitness & Nutrition	N	N
Easy DNA	easydna.ie	NutriFit Health & Fitness DNA Testing	N	N
Fitness Genes	**fitnessgenes.com**	**DNA Analysis**	**Y**	**N**
Found My Fitness	foundmyfitness.com	Found My Fitness Comprehensive Report	N	N
Genetic Direction	**geneticdirection.com**	**GxPerform**	**Y**	**Y**
Genovate	**genovate.com**	**DNA Fitness Test**	**Y**	**N**
GenoVive	genoviveusa.com	Nutrition and Fitness Genetic Profile Report	N	Y
Health Codes DNA	healthcodesdna.com	Fitness Panel	N	N

Helix	helix.com	MyTraits Sport for iOS	N	N
HomeDNA	**homedna.com**	**HomeDNA Healthy Weight**	**Y**	**Y**
IDLife	idlife.com	DNA Bundle	N	N
LifeDNA	lifedna.com	LifeDNA Reports + DNA Kit	N	Y
MiaDNA	miadna.com	Exercise & Fitness	N	N
Molecular Fitness	mtlfitness.com	Molecular Fitness	N	Y
myDNA	**mydna.life/en-us**	**Nutrition & Fitness**	**Y**	**Y**
MyExome	myexome.com	DNA Testing for Fitness, Nutrition and Health	N	N
Myogenes	myogenes.com	Diet, Health & Fitness Test	N	N
New Life Genetics	**newlifegenetics.com**	**DNA Fitness Test for Men, DNA Fitness Test for Women**	**Y**	**N**
Next Health	next-health.com	Genetic Fit Testing	N	N
Ori	askori.com	OriFIT + Package	N	N
Orig3n	**shop.orig3n.com**	**Fitness DNA Test**	**Y**	**N**
Original Gene	originalgene.com	Fitness & Healthy Living DNA Test	N	N
Vitagene	vitagene.com	Health Plus Ancestry Report	N	N
Vitl	vitl.com	DNA Nutrition Test	N	N
Xcode	xcode.life	Gene Fitness Report	N	N

Table 2 - All Genes Identified by DTC Genetic Fitness Testing Websites

ABCB11	CKM	GLIS1	LRRN6C	PPARG
ACE	CLOCK	GNB3	MAP2K5	PPARGC1
ACTG1	CNTF	GNPDA2	MBL2/DKK1	PPM1K
ACTN3	COL1A1	GPRC5B	MC4R	PRKD1
ACVR1B	COL5A1	GPX1	MCT1	QPCTL-GIPR
ADH1C	COMT	GSTM1	MEPE	RP11-10017.3-001
ADIPOQ	CREB1	GSTT1	MGMT	RPL27A

ANALYSIS OF DTC GENETIC FITNESS TESTS

ADORA2A	CRP	HERC2	MSTN	SEC16B
ADRB2	CRP	HIF1A	MSTNRARE	SHBG1
ADRB2_1	CRY2	HLA	MTCH2	SHBG2
ADRB2_2	CYP1A1	HLA	MTHFR	SHBGE7
ADRB3	CYP1A2	HNF1A	MTHFR_SNP2	SLC23A1
AGT	CYP2R1	HOXB3	MTIF3	SLC25A13
AHR	DEC(1)	IGF1	MTNR1B	SLC30A8
AKT1	DRD2	IGF1_2	MTR	SLC39A8
ALDH2	EC16B	IGFBP3	MTRR	SLC8A1
AMPD1	EDN1	IGFS9B	NADSYN1	SOD2
ANNK1	EPHX1	IL15RA	NBPF3	SPTBN1
APOA2	ERP27	IL6	NEGR1	SYT1
APOA5	ETV5	IL6R	NFE2L2	TCF7L2
APOC1 (APOE-CI-CII)	FABP2	IRS1	NMB	TFAP2B
APOC3	FAIM2	KANSL1	NOS3	TGFA
APOE	FANCL	KIF5B	NRF2	TNF
ARID3B	FLJ35779	LCT	NRXN3	TRHR
BCM01	FTO	LIPC	PEX14	UCP2
BDKRB2	FUT2	LPL	PGC1A	UCP3
BDNF	GBF1	LRP1B	POLD3	VDR
C18orf19	GC	LRP5	PPARA	VDR_Taq
CAT	GDF5	LRPPRC	PPARD	VEGF/VEGFA

Figure 1 - Percentages of the 8 DTC Genetic Fitness Testing Companies that List MCGT

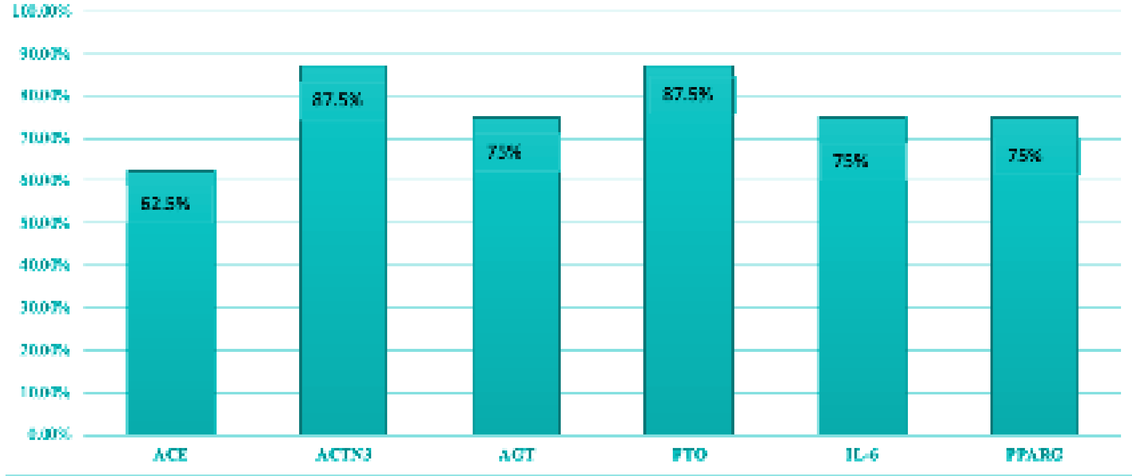


Figure 2 - Percentages of DTC Genetic Fitness Testing Companies Citing Scientific Literature

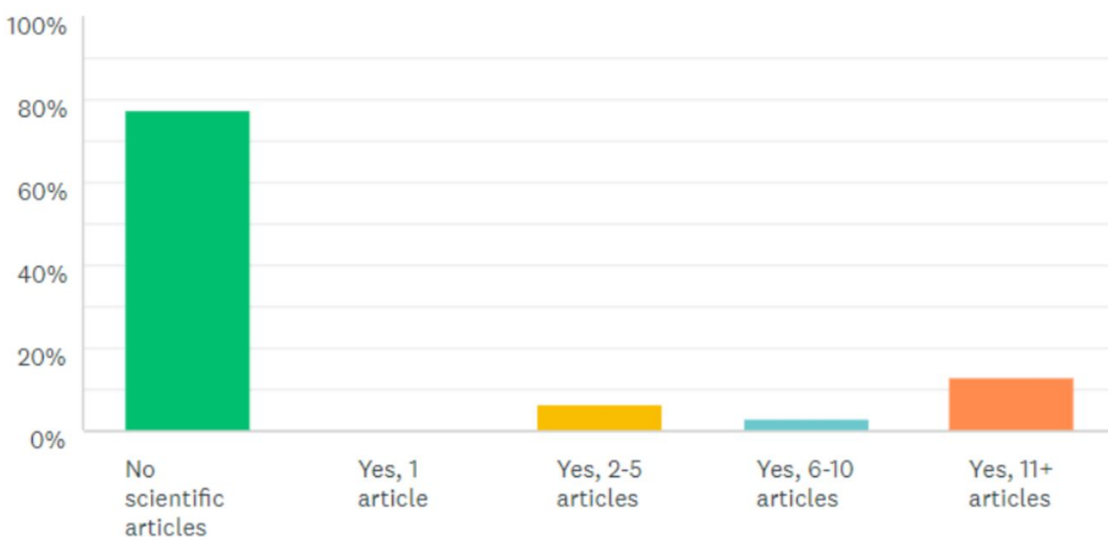


Figure 3 - Top Claims of DTC Genetic Fitness Testing Companies

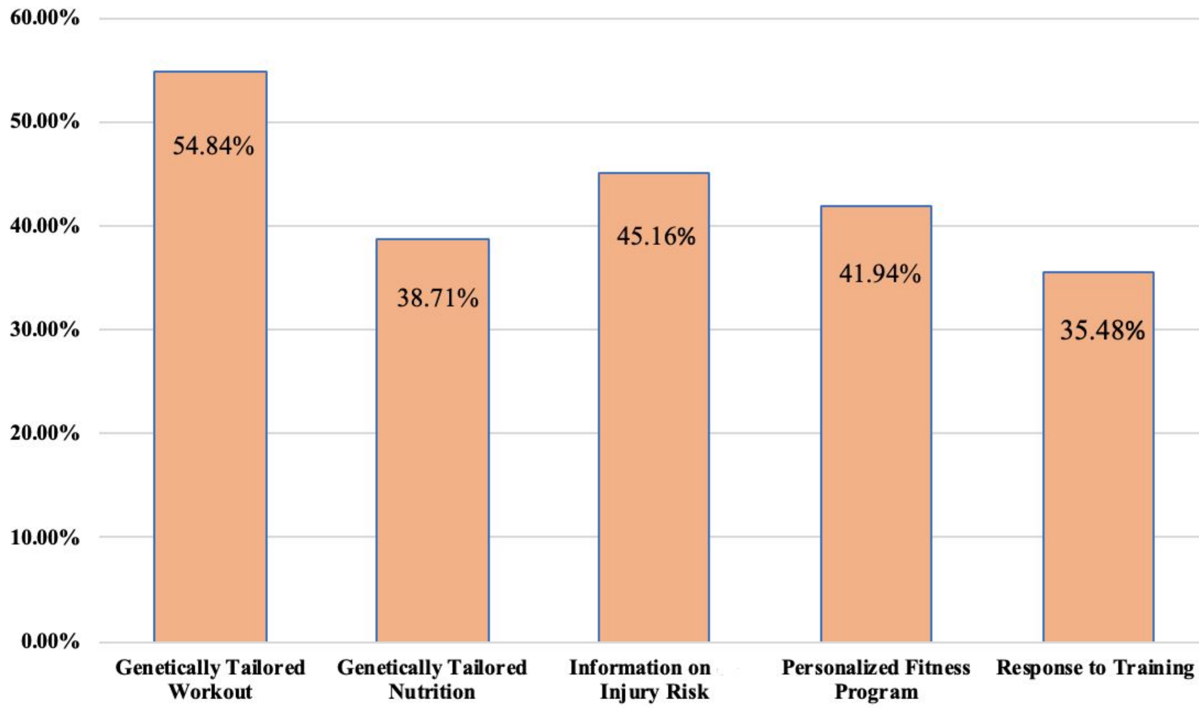
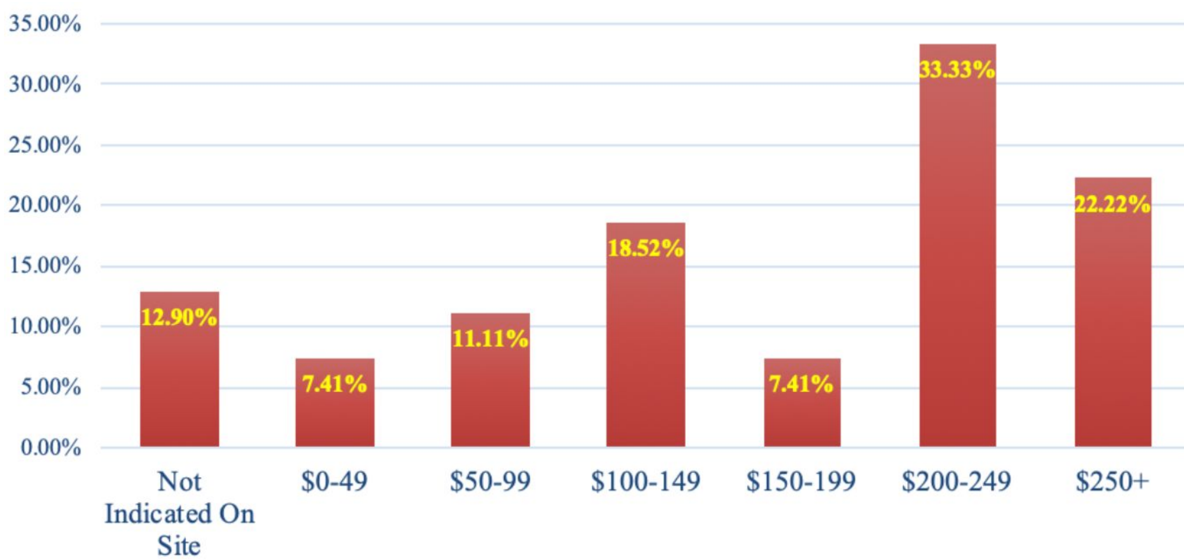


Figure 4 - Cost of DTC Genetic Fitness Tests



Discussion

Our analysis showed that of 31 DTC genetic fitness tests found online, only 8 companies attempted to inform consumers on what genes were included in the test. Without knowledge of what genes are being examined, no consumers and no experts can assess the value of the tests for sale from those 23 companies, many of which carry a substantial price tag. Among those 8 that do list the genes examined, only half offered any references to scientific literature to support their choice of targets. Further consideration of the utility of testing, therefore, was only possible for four companies that provided both the genes tested and literature to support a scientific rationale for testing.

Genetic Direction. All of the 6 MCGT are tested here; however, literature was supplied only for *ACE, ACTN3, AGT,* and *IL6*. The study available (Weyerstraß, Stewart, Wesselius, & Zeegers, 2018) on the website concluded that there is an association between being a power athlete and certain alleles; yet, the authors also suggest that more research is needed on these genes to come to any comprehensive conclusions. Despite this caveat, Genetic Direction still makes 3 of the 5 MCC: genetically tailored workout, personalized fitness program, and training response.

HomeDNA. Of the 6 MCGT, HomeDNA only looks at *FTO* and *PPARG* and which, surprisingly, was noted to not make the claim of genetically tailored nutrition. Instead, the MCC made are genetically tailored workout and personalized fitness program. Noted researcher Dr. Mark Sarzynski is credited for his research efforts for HomeDNA, but he is also part of the Genetic Direction leadership team.

myDNA. Five of the MCGT are offered by myDNA: *ACTN3, AGT, FTO, IL6* and *PPARG.* Scientific literature available on the site mentions *ACTN3* (Kikuchi & Nakazato, 2015), *AGT* (Zarebska et al., 2013), and *IL6* (Ruiz et al., 2010), among others, for muscle fiber composition as well as a study showing the absence of any association between certain genotypes and sprint/power performance (Ahmetov, Vinogradova, & Williams, 2012). Importantly, myDNA is the only website to list two employed associate genetic counselors on their team, but their scope of practice is not discussed.

The MCC genetically tailored nutrition, information on injury risk, and personalized fitness program are made; furthermore, statements are made about the gene variants that myDNA tests for but the specific variants are not stated. For example, myDNA calls ACTN3 ‘The Power Gene’ and incorrectly states that elite athletes will generally possess the variant of this gene associated with explosive fitness movements. It is true that there is an association between elite power athletes and the *RR* genotype for explosive movements; yet, not all elite athletes will have the *RR* genotype nor will every sport call for the use of fast-twitch muscle fibers. *AGT* is called ‘The Strength Gene’ and there have been claims that the associated genetic variant is most commonly found in power sport Olympians, but this has not been verified. *IL6* is called ‘The Recovery Gene’ and there have been claims that the associated genetic variant helps the body recover faster from intense exercise, and while this is plausible, it has not been documented in the literature in studies of athletes. *FTO* and *PPARG* are related to food satiety and fat storage, respectively, and are described as much on myDNA’s website with marketing claims such as the *FTO* gene may be the reason why someone goes back for seconds at the dinner table.

DNAfit. All of the 6 MCGT are mentioned on the website and scientific references are present, the latest from 2019 (Pickering et al.). Authors of the literature cited included two employees of DNAfit: Dr. Ildus Ahmetov and Dr. Silvia Camporesi from DNAfit's Scientific & Advisory Team. It is not indicated when Dr. Ahmetov or Dr. Camporesi became employees of DNAfit or if their publications were done prior or after that relationship was established.

The MCC of genetically tailored workout, information on injury risk, personalized fitness program, and response to training are made, and akin to myDNA, these claims are tied to the genes that DNAfit tests for. This time, however, actual alleles are discussed in such a way to aid consumers who are interested in assessing their genetic basis workout recommendations.

According to DNAfit, the *I* and *D* alleles of *ACE* are the basis of different workout recommendations: the *I/I* alleles associated with endurance sports and high repetition weight training programs and the *DD* alleles associated with power based training. These findings have been seen in the literature but are not without controversy, as some studies showed no significant effect of the *II* alleles in endurance training. DNAfit makes claims about *ACTN3* while incorrectly labeling the alleles they are looking at, identifying the *RR* and *XX* alleles as *CC* and *TT*, respectively. The claim made here of the *XX* genotype being found more frequently in endurance athletes is not supported in the literature, while the claim that people with the *RR* genotype are likely to see increased benefit from explosive training is more extensively supported. Claims that *AGT* alleles are associated with power and strength sports and *IL6* alleles with inflammatory responses are supported by literature. Additionally, claims for alleles associated with fat sensitivities from *FTO* and *PPARG* are relatively well supported by the literature as well.

Study Limitations

This study examined only the information available to a consumer before a test is purchased. Purchasing tests from a sample of DTC genetic fitness companies would have permitted us to assess how results are presented and what explanatory information is available and how that compares to relevant scientific literature.

Practice Implications

Our study suggests that those purchasing these tests for recreational purposes should be aware that the tests, often expensive, provide almost entirely inconclusive results. Ideally, consumers may be made aware that all DTC companies are not created equal and this study may provide a helpful guide for their own research and comparison shopping. Additionally, this work may provide genetic counselors with an up to date reference for answering questions about the types and limitations of genetic fitness tests.

Research Recommendations

More scientific research is still needed to better understand genetic differences associated with athletic traits. It appears there is a consensus in the scientific community regarding the inherent predictive limitations of the current data on polymorphisms related to athletics—including the most well established as well as the more controversial associations. Larger, racially diverse cohorts are needed as well as cohorts with varying athletic levels, from people who do not work out at all to those who are not elite athletes, but workout three to five times per week. DTC genetic fitness testing for athletic ability may eventually play a useful role in an assessment of fitness potential. However, the scientific community is rightly concerned about the legitimacy of what companies are marketing and selling the consumer as representing the general population (as opposed to elite athletes). Given the lack of basic information available on the websites, we cannot fully assess the basis of their claims, and can only generally express skepticism about the product as being limited in value according to what is currently known. DTC genetic testing companies should be encouraged to be more honest and transparent in reporting what their tests cover and what the results may mean for each individual.

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